DOUBLE CROPPING WITH WINTER CEREALS AND FORAGE SORGHUM IN NEW YORK

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Forage production in New York is primarily for dairy operations and typically includes one main crop per growing season. The most common forage rotations in New York include corn silage (*Zea mays* L.) and alfalfa (*Medicago sativa* L.)/grass hay mixtures rotated every three-to-four years. If the ground is left bare over the winter months following corn silage harvest, it enhances risk of soil erosion and nutrient loss. Double cropping with forage winter cereals during the corn silage years can help with soil conservation and nutrient recycling as well as provide additional yield in the spring. Four studies were conducted to determine the nitrogen (N) needs and best time of planting of winter cereals grown for forage in New York. The objectives of the first study (Chapter 1) were to evaluate the impact of fall planting date and N availability on biomass production and N uptake of triticale (x *Triticosecale* Wittm.). Earlier planted triticale was better able to take up additional N due to increased fall biomass accumulation. The second study (Chapter 2) concluded that N applied to triticale at spring dormancy break was more important for spring yield and forage protein than fall N availability. In Chapter 3, a stepwise method for characterizing yield response to N application was developed and statistical models for determining the most economic rate of N (MERN) based on 62 forage winter cereal N-rate trials were evaluated. The quadratic plateau model was the best option based on both statistical and environmental criteria. The 62 N-rate trials were then used to

determine a model for predicting the MERN based on field characteristics and management practices (Chapter 4). Soil drainage, recent manure applications, and planting date were selected as important indicators for the MERN. Because forage winter cereal planting and harvest can overlap with the corn silage growing season, forage sorghum [*Sorghum bicolor* (L.) Moench] was evaluated in three studies as a potential alternative warm-season silage crop. A sorghum N-rate study with 13 trials determined that yield response to N fertilizer fell into three groups: (1) no response (MERN = 0), (2) no yield plateau (MERN > highest N rate), and (3) a yield plateau between the lowest and highest N rates (Chapter 5). The sorghum required approximately 10 kg N ha^{-1} per 1 Mg DM ha^{-1} yield. For seven of these trials, multiple harvests took place to evaluate if sorghum harvest can take place earlier in the fall without reducing yield or nutritive value (Chapter 6). It was concluded that forage sorghum can be harvested at the late flower to early milk stage while maintaining yield and improving fiber digestibility and crude protein. However, if forage sorghum is included in a dairy diet, additional energy supplementation may be needed due to lower starch content at less mature growth stages. A two-year double crop rotation study with forage sorghum and triticale was implemented to determine the optimal harvest time of sorghum and N management of both sorghum and triticale for full-season yield (Chapter 7). Fertilizing sorghum according to N needs and timely harvest supported both sorghum and triticale without having to fertilize the triticale in the spring. Double cropping in New York can be an environmentally and economically beneficial practice if managed properly.

BIOGRAPHICAL SKETCH

Sarah Elizabeth Lyons was born in West Palm Beach, Florida, where she lived for nearly thirteen years before moving to the mountains of Western North Carolina. She graduated 4th in her class from West Henderson High School before continuing on to study biology at Furman University in Greenville, South Carolina. While completing her undergraduate education, Sarah volunteered on a small farm where she became interested in agricultural research. After graduating with honors and earning a Bachelor of Science degree in biology, she moved to Raleigh to pursue a Master of Science degree in Animal Science at North Carolina State University with a focus on fescue toxicity in pasture-based beef cattle. Following the completion of her Masters work, Sarah was offered an assistantship at Cornell University to pursue a Ph.D. in Animal Science with a focus on forage production on dairy farms in New York. Her Ph.D. research aimed to determine nitrogen recommendation systems and best management practices for forage sorghum and forage triticale grown in double crop rotations in the Northeast. After completing her Ph.D., Sarah will begin a position as a Postdoctoral Research Scholar in the Department of Crop and Soil Sciences at North Carolina State University.

This dissertation is dedicated to my mom, Sue Lyons, my greatest role model and very best friend, who makes the world a more beautiful place every day.

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LIST OF ABBREVIATIONS

ADF: Acid detergent fiber

ANR: Apparent nitrogen recovery

BMR: Brown midrib

Ca: Calcium

CNCPS: Cornell Net Carbohydrate and Protein System

CP: Crude protein

DM: Dry matter

GDD: Growing degree days

HG: Hydrologic group

ISNT: Illinois Soil N Test

IVTD: In vitro true digestibility

K: Potassium

LOI: Loss on ignition

MERN: Most economic rate of nitrogen

Mg: Magnesium

Mn: Manganese

N: Nitrogen

NDF: Neutral detergent fiber

$NDFD_{30}$: Neutral detergent fiber digestibility, 30 h fermentation

$NDFD_{48}$: Neutral detergent fiber digestibility, 48 h fermentation

NFC: Non-fiber carbohydrates

NUE: Nitrogen use efficiency

P: Phosphorus

SMG: Soil management group

SOM: Soil organic matter

TDN: Total digestible nutrients

TMR: Total mixed ration

Zn: Zinc

CHAPTER 1: EARLY FALL PLANTING INCREASES GROWTH AND NITROGEN UPTAKE OF WINTER CEREALS[1]

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ABSTRACT

Winter cereals such as triticale (x *Triticosecale*) have shown to be excellent cover and double crops in the northeastern United States due to beneficial environmental and economic qualities, including the potential to scavenge residual N and take up N from fall-applied manure. Total fall N uptake is impacted by fall seeding date and available N supply. Here we determined the impact of fall planting date and available N on pre-frost biomass accumulation and N uptake of triticale. Two planting dates, ranging from late August to early October, were evaluated at four locations in upstate New York. Trials were arranged in a split-plot design, with planting date as the main treatment and N application rate (0, 34, 67, 101, 135 kg N ha^{-1}) as the split plot treatment. All plots were harvested in November prior to frost. With no added N, earlier planting (before 20 September), on average, resulted in 21% greater biomass

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Lyons, S.E., Q.M. Ketterings, G. Godwin, J.H. Cherney, K.J. Czymmek, and T. Kilcer. 2017. Early fall planting increases growth and nitrogen uptake of winter cereals. Agron. J. 109:1-7. doi:10.2134/agronj2016.10.0620

and 45% greater N uptake. Nitrogen addition did not increase biomass or fall N uptake for later planting dates, averaging 13 to 30 kg N ha^{-1} across all sites. Earlier planting dates had greater nitrogen use efficiency (NUE) and apparent nitrogen recovery (ANR), with an average N uptake of 70 to 90 kg N ha^{-1}, suggesting early planted triticale can scavenge nutrients leftover from the previous crop and provide a more environmentally friendly opportunity for spreading manure in the fall. Additional research is needed to examine the potential for N loss in these scenarios.

INTRODUCTION

New York is ranked fourth in the United States for milk production (National Agricultural Statistics Service, 2015), and the majority of field crops grown in the state is harvested as forage for dairy cattle. A typical rotation of forage crops on dairy farms is 3 to 4 yr of corn (*Zea mays* L.) followed by 3 to 4 yr of alfalfa (*Medicago sativa* L.) or an alfalfa/grass mixture. Because of the long winters and relatively short growing seasons in the northeastern United States, crop production on dairy farms typically consists of only one main crop per growing season, which often leads to bare ground over the winter months following corn silage harvest. In more recent years, a growing number of dairy producers have adopted the practice of planting cover crops between corn silage years, which can reduce the risk of soil erosion, enhance soil organic matter, improve rotation diversity, and reduce nutrient loss to the environment through plant uptake of nutrients applied to but not used by the main crop (Dabney et al., 2001; Long et al., 2013; Ketterings et al., 2015b). Harvesting the cool season crop for forage in the spring, hereafter referred to as double cropping, is also becoming a practice of greater interest for dairy producers given its potential to increase whole season yield and supply forages in late spring (Ketterings et al., 2015a). Planting a cover or double crop in the fall could aid in reducing environmental issues associated with fall application of manure, such as N leaching and P runoff, by taking up readily available nutrients in the fall (Shipley et al., 1992; Dabney et al., 2001; Rufo et al., 2004; Fang et al., 2006).

Winter cereals such as cereal rye (*Secale cereale* L.) and triticale, typically considered good cover or double crop options in the Northeast, have a greater capacity to take up residual soil N in the fall than cover crops such as hairy vetch (*Vicia villosa* Roth), crimson clover (*Trifolium incarnatum* L.), and other legumes. This may be due to differences in root morphology and root hair volume (Shipley et al., 1992), as well as the N-fixing ability of legumes. Cereal rye is better adapted to cool, dry conditions as compared to hairy vetch, crimson clover and annual ryegrass (*Lolium multiflorum* Lam.), and thus is quicker to establish in the fall thereby increasing its capacity to scavenge residual N (Wagger and Mengel, 1998; Ditsch and Alley, 1991; Shipley et al., 1992; Bollero and Bullock, 1994). Triticale, a hybrid of wheat (*Triticum aestivum* L.) and rye, is a winter cereal that is used as a double crop in the Northeast, and likely shares many of the beneficial properties associated with cereal rye mentioned above. Shipley et al. (1992) estimated that cereal rye recovered 60% of residual soil N in the fall following a 336 kg N ha^{-1} N rate applied on the previous corn crop, which amounted to 64 kg N ha^{-1} conserved. In humid climates, this will reduce N loss to the environment as shown by Meisinger et al. (1991), who reported that planting cereal rye as a cover crop led to a 59 to 77% reduction in leached N as compared to bare ground.

Although the benefits of planting a winter cereal are recognized, it can be challenging for farmers to implement the corn silage and winter cereal double cropping system in the Northeast given the relatively short growing season and early onset of frost. In New York, first frost can occur as early as mid-September, and typically occurs by mid-October. Corn silage harvest occurs when the crop contains around 650 g kg^{-1} moisture, which can be as late as the end of September or early October, depending on planting dates, growing conditions, and varieties. Late planting of a winter cereal may reduce fall biomass accumulation, most likely reflecting the shorter growing window, reduced day length, and cooler temperatures when seeding is late, and thus limit the potential for scavenging N leftover from the corn crop. Ideally winter cereals like cereal rye or triticale are planted mid-September. Especially for cereal rye, planting can in many years take place through early November, but such late planting often results in little or no fall growth. Harvest of winter cereal silage at flag-leaf or boot stage usually occurs in late May in the Northeast, past the ideal planting time for corn silage in late April or early May, though shorter-day corn varieties can be planted through early June. A delay in corn silage planting will often result in a later harvest as well, potentially delaying fall cereal planting.

Research on winter cereal establishment and growth when seeded after corn silage harvest on dairy farms is scant. Given a growing interest among farmers to seed triticale after corn silage harvest, additional studies are needed to quantify triticale's ability to take up N as impacted by planting date. The objectives of this study were to determine the impact of fall planting date and N availability on the growth and N uptake of triticale grown as a double crop in dairy forage rotations in New York.

MATERIALS AND METHODS

Locations and Experimental Design

Field trials were conducted at the Valatie Research Farm in Columbia county, New York, in 2012 (trial A), 2013 (trial B), and 2014 (trial D), and at the Varna Research Farm in Tompkins county, New York, in 2013 (trial C). The soil type at the Valatie Research Farm is an outwash-derived Hoosic gravelly loam (sandy-skeletal, mixed, mesic Typic Dystrudepts). At the Varna location, the soil type is a Hudson silty clay loam (fine, illitic, mesic Glossaquic Hapludalfs). For Varna, the triticale followed cereal rye, while for Valatie the triticale followed corn or sorghum depending on the year. Weather data were collected at the Copake weather station in Columbia county, approximately 50 km from the Valatie Research Farm, and the Cornell University research station in Tompkins county, approximately 5 km from the Varna Research Farm. There was less precipitation than normal for trial D in September (24 mm vs. the normal 98 mm) and trial B in October (28 mm vs. the normal 96 mm), and more precipitation than normal for trial C in August (133 mm vs. the normal 86 mm) and trial A in September (178 mm vs. the normal 98 mm); for all other months, average temperatures and total monthly precipitation were approximately normal (Table 1.1).

Table 1.1. Monthly precipitation and temperature for four winter triticale trials conducted in New York in the fall of 2012, 2013, and 2014. Data were obtained from within-county weather stations (Northeast Regional Climate Center, 2016). The average monthly temperature is determined from calculated daily averages [(maximum daily temperature – minimum daily temperature)/2].

Trial	Year	August	September	October	November
Total monthly precipitation		---------- mm	----------	----------	----------
A	2012	71	178	81	38
	Normal†	99	108	107	84
B	2013	89	84	28	33
	Normal†	99	108	107	84
C	2013	133	96	68	92
	Normal†	93	96	82	77
D	2014	73	24	106	64
	Normal†	99	108	107	84
Average monthly temperature		---------- °C	----------	----------	----------
A	2012	22.1	15.9	11.8	4.5
	Normal†	20.6	16.2	9.6	4.4
B	2013	18.5	16.2	11.9	5.6
	Normal†	20.6	16.2	9.6	4.4
C	2013	18.7	14.3	10.8	2.1
	Normal†	19.7	16.2	9.6	4.1
D	2014	18.5	16.3	13.0	3.6
	Normal†	20.6	16.2	9.6	4.4

†Normal values are averages of monthly values from 1982 to 2015 for trial C and from 1982 to 2014 for trials A, B, and D.

The trials were organized in randomized complete split-plot designs, with planting date as the main treatment (two planting dates per trial; four replications), and N application rate as the subplot treatments (0, 34, 67, 101, and 135 kg N ha^{-1}). Nitrogen was broadcast as AGROTAIN®ULTRA-treated urea (Koch Agronomic Services, LLC, Wichita, KS) at planting. One soil composite per replication, consisting of 20 cores (0- to 200-mm depth), was taken at planting prior to fertilization to determine baseline soil fertility parameters.

Planting and Harvest

Planting took place on 10 September and 5 October for trial A, 20 and 30 September for trials B and C, and 25 August and 10 September for trial D. Triticale (Trical 815, King's AgriSeeds Inc., Ronks, PA) was drilled at a 2.54 cm depth at 135 kg seeds ha^{-1} with 19.5 cm row spacing. Plots were 2 m wide by 4 m long (0.005 ha) and contained 10 rows per plot. Three 0.98 by 0.20 m frames (0.186 m^2) that contained five rows each were hand harvested to determine total aboveground biomass accumulation in late November just prior to frost, and biomass was subsampled to determine moisture content, total biomass, and N content.

Soil and Forage Analysis

Triticale biomass was dried and ground to pass a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) and submitted to Cumberland Valley Analytical Services (Hagerstown, MD) for total N determination using near infrared reflectance spectroscopy (NIR) analysis (Marten et al., 1989) using a FOSS 5000 NIR

(FOSS, Eden Prairie, MN). Soil composites were dried at 50°C and ground to pass through a 2-mm screen and submitted for baseline fertility parameters (Analytical Laboratory and Maine Soil Testing Service, Orono, ME). Soil pH was measured in a 1:1 (w/v) water extract, and soil organic matter (OM) was determined by loss-on-ignition through exposure to 500°C (Storer, 1984). The Cornell Morgan soil test was used to extract P, K, Mg, Ca, Mn, and Zn by shaking dried samples in a 1:5 (v/v) ratio for 15 min in Morgan solution (1 M sodium acetate buffered at pH 4.8; Morgan, 1941). The extracts were filtered through a Whatman No. 2 equivalent filter paper following procedures outlined in NEC-1012 (Northeast Coordinating Committee for Soil Testing, 2011). The filtered extracts were analyzed for K, Mg, Ca, Mn and Zn using an inductively coupled plasma atomic emission spectrometer (ICP-AES, JY70 Type II, Jobin Yvon, Edison, NJ). Phosphorus was determined colorimetrically using the ammonium molybdate-ascorbic acid method (Knudsen and Beegle, 1988) with a Lachat QuikChem® 8000 flow injection analyzer (Lachat Instruments, Milwaukee, WI). Soil pH ranged from 5.6 to 6.6, acceptable for triticale. Soil organic matter ranged from 20 to 33 g kg^{-1}. Soil test P and Mg were high for all trials, while K was high for the Valatie trials and very high for the Varna trial according to soil fertility interpretations of Cornell University (Cornell Cooperative Extension, 2016).

Statistical Analysis

Trials were analyzed individually as a split-plot design using PROC MIXED of SAS (SAS Institute, 1999), with planting date as the main treatment and N application rate (0, 34, 67, 101, 135 kg N ha^{-1}) as the split plot treatment. Planting date and N rate were included as fixed effects and year and replication as random effects. Interactions between planting date and N rate were investigated. When no interactions were present, models were re-run including main effects only. Quadratic regressions were employed using PROC REG of SAS to determine the yield plateau for each trial, using a quadratic plateau model where response to N was significant. Significance was determined when $P \leq 0.05$, and trends were determined when $P \leq 0.1$.

Nitrogen use efficiency and ANR were determined for each N application rate. The NUE represents the increase in DM yield per kg N added (Eq. 1.1) while ANR indicates the N removal in harvest per kg N applied (Eq. 1.2) (Ketterings et al., 2007):

$$\text{NUE (kg DM kg}^{-1}\text{ N)} = (\text{DM at } N_{rate} - \text{DM at control})/\text{N applied} \qquad [1.1]$$

$$\text{ANR (\%)} = (\text{N at } N_{rate} - \text{N at control})/(\text{N applied}) \times 100 \qquad [1.2]$$

RESULTS AND DISCUSSION

Planting Date, Nitrogen Rate, and Fall Growth

Where no N was added, trial A averaged 1.2 Mg DM ha^{-1} when seeded 10 September and 0.4 Mg DM ha^{-1} when seeded 5 October (Figure 1.1). Similarly, at trial B, total biomass was 1.3 Mg DM ha^{-1} for the 20 September seeding and 0.6 DM ha^{-1} for the 30 September planting. At trial C, total biomass was lowest of all trials and did not increase, averaging 0.3 and 0.4 Mg DM ha^{-1} for the 20 September and 30 September planting dates, respectively.

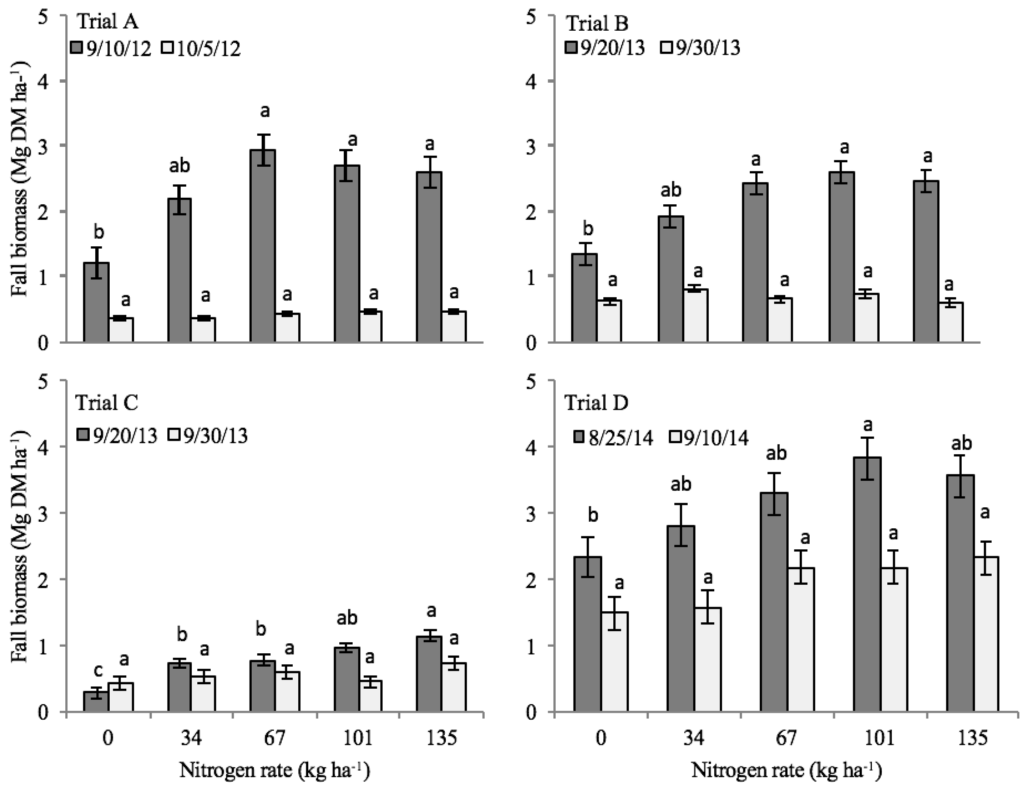

Figure 1.1. Effect of planting date and nitrogen (N) rate on triticale fall biomass accumulation for four trials in New York (n = 160). Triticale was harvested in late November just before snowfall for each trial. At three of the four locations (trials A, B, and C), there was a significant interaction between planting date and N rate. Error bars represent 1 SE, and the different letters within each trial and planting date represent significant differences in biomass ($P \leq 0.05$).

At this location, soil nutrient levels were adequate but temperatures were lower in September, October, and November, and rainfall was scarce after planting (between 15 September and 5 October) as compared to the Valatie locations (Tables 1.1 and 1.2). The highest yields were obtained for trial D with an average yield of 5.2 Mg DM ha^{-1} for the 25 August and 3.3 Mg DM ha^{-1} for the 10 September planting date. Overall, our results show that triticale planted prior to 20 September on average produced 3.3 Mg DM ha^{-1} fall growth, compared to an average of 0.6 Mg DM ha^{-1} fall growth if planted after 20 September. These results are similar to those reported by Ort et al. (2013) where triticale planted before September 20 yielded, on average, 1.59 Mg DM ha^{-1} aboveground biomass in the fall, with biomass reaching 3.6 Mg DM ha^{-1} at one location. Trials planted after 20 September in Ort et al. (2013) averaged 0.45 Mg DM ha^{-1} in the fall, ranging from 0.18-1.2 Mg DM ha^{-1}, consistent with our findings.

Table 1.2. Baseline soil characteristics for four winter triticale trials conducted in New York in the fall of 2012, 2013, and 2014. Values are averages of four 0- to 20-cm core soil samples within each trial. The Cornell Morgan soil test method (Morgan, 1941) was used for all nutrients.

Trial	Planting date	pH	OM	P	K	Mg	Ca	Mn	Zn
			g kg^{-1}	------------------------ mg kg^{-1}	---------------------------				
A†	9/10/12	6.5	33	6.8 (H)	79 (H)	145 (VH)	1178	5.9	0.3 (M)
A†	10/5/12	6.5	33	6.8 (H)	79 (H)	145 (VH)	1178	5.9	0.3 (M)
B	9/20/13	6.6	26	5.9 (H)	89 (H)	134 (VH)	1105	19.1	0.2 (L)
B	9/30/13	6.6	25	4.6 (H)	91 (H)	129 (VH)	952	17.9	1.0 (H)
C	9/20/13	5.7	22	13.8 (H)	134 (VH)	105 (VH)	819	17.1	0.4 (M)
C	9/30/13	5.6	20	13.3 (H)	134 (VH)	106 (VH)	811	20.0	0.4 (M)
D†	8/25/14	6.5	33	6.8 (H)	79 (H)	145 (VH)	1178	5.9	0.3 (M)
D†	9/10/14	6.5	33	6.8 (H)	79 (H	145 (VH)	1178	5.9	0.3 (M)

†Only one set of soil analyses done for both planting dates; Trials A and D were located on a larger field for which a composite soil sample was analyzed. Morgan soil test interpretations: L = Low, M = Medium, H = High, VH = Very High.

At three of the four locations (trials A, B, and C), there was a significant interaction between planting date and N rate on biomass (Figure 1.1). At each of these locations, planting by 20 September resulted in a biomass response to N application, with biomass ranging from 0.3 to 1.3 Mg DM ha^{-1} with no N applied to 0.7 to 2.9 Mg DM ha^{-1} with N application. At trial D, at the 25 August planting date, biomass ranged from 2.3 Mg DM ha^{-1} when no N was applied to a maximum of 3.8 Mg DM ha^{-1} of biomass with N addition. In comparison, for the 10 September planting date at trial D, biomass increased from 1.5 Mg DM ha^{-1} with no N to a maximum of 2.3 Mg DM ha^{-1} with N addition. The lack of interaction between N rate and planting date at trial D reflects a significant N response for the 25 August planting date ($P = 0.03$) and a similar trend for the 10 September planting date ($P = 0.08$), consistent with the fact that both plantings were done prior to 20 September.

The N rates at which a biomass plateau occurred for the earlier planting dates (on or before 20 September) were 92 kg N ha^{-1} for trial A and 107 kg N ha^{-1} for trial B. For the earlier planting dates in trials C and D, biomass continued to increase with increasing N application (Table 1.3). For the later planting dates in all trials (after 20 September), N addition did not result in an increase in yield at $P \leq 0.05$ with biomass ranging from 0.35 to 0.75 Mg DM ha^{-1} across all N treatments (Figure 1.1). However, the yield results suggested a trend toward slightly higher yields with N addition ($P \leq 0.1$ for all four sites). These results suggest that dry matter accumulation is primarily a function of planting date, with much smaller gains in biomass when triticale is planted after September 20.

Table 1.3. Rate of nitrogen (N) at which the yield reached a plateau, and the yield, N use efficiency (NUE) and apparent N recovery (ANR) at the plateau for four triticale trials in New York conducted in the fall of 2012, 2013, and 2014.

Trial	Planting date	N rate at yield plateau	Yield at yield plateau	NUE at yield plateau	ANR at yield plateau
		kg N ha^{-1}	Mg DM ha^{-1}	kg DM kg N^{-1}	%
A	9/10/12	92	4.53	9.2	57.7
A	10/5/12	na†	0.42‡	0.2‡	0.2‡
B	9/20/13	107	1.15	5.7	56.0
B	9/30/13	na†	0.69‡	0.9‡	9.2‡
C	9/20/13	>135§	1.15¶	2.6¶	29.1¶
C	9/30/13	na†	0.55‡	0.9‡	5.1‡
D	8/25/14	>135‡	7.98¶	13.2¶	28.3¶
D	9/10/14	na§	4.37‡	6.4‡	26.9‡

†na, not applicable
‡Average value across all N rates.
§Yield plateau could not be determined as yield increased linearly with additional N.
¶Value obtained at maximum N rate (135 kg ha^{-1}).

Planting Date, Nitrogen Rate and Nitrogen Uptake

As with fall biomass accumulation, there was an interaction between planting date and N rate on forage N uptake for trials A, B, and C (Figure 1.2). When planted before 20 September at these trials, N uptake averaged 24 kg N ha^{-1} and ranged from 7 to 35 kg N ha^{-1} when no N was applied, but averaged 65 kg N ha^{-1} and ranged from 20 to 98 kg N ha^{-1} when N was added. There was no interaction between planting date and N rate for trial D ($P = 0.70$); forage N uptake tended ($P = 0.07$) to increase with N application for the 25 August planting date in this trial as well. Trial D had N uptake values ranging from 76 to 124 and 55 to 81 kg N ha^{-1} for the 25 August and 9 September planting dates, respectively. Plots planted after 20 September had no differences in N uptake among treatments, and ranged from 13 to 36 kg N ha^{-1} with an average of 21 kg N ha^{-1} across locations. These findings are consistent with Ort et al. (2013) who reported an average N uptake of 54 kg ha^{-1} of N in the above ground portion of triticale plants when seeded prior to September 20, while the trials planted after September 20 averaged 17 kg N ha^{-1} uptake. Trials with larger uptake values had received additional N through surface-applied manure. Similarly, another triticale study conducted in western New York where triticale was planted after September 20 showed an average uptake of 28 kg N ha^{-1} (Ketterings et al., 2011).

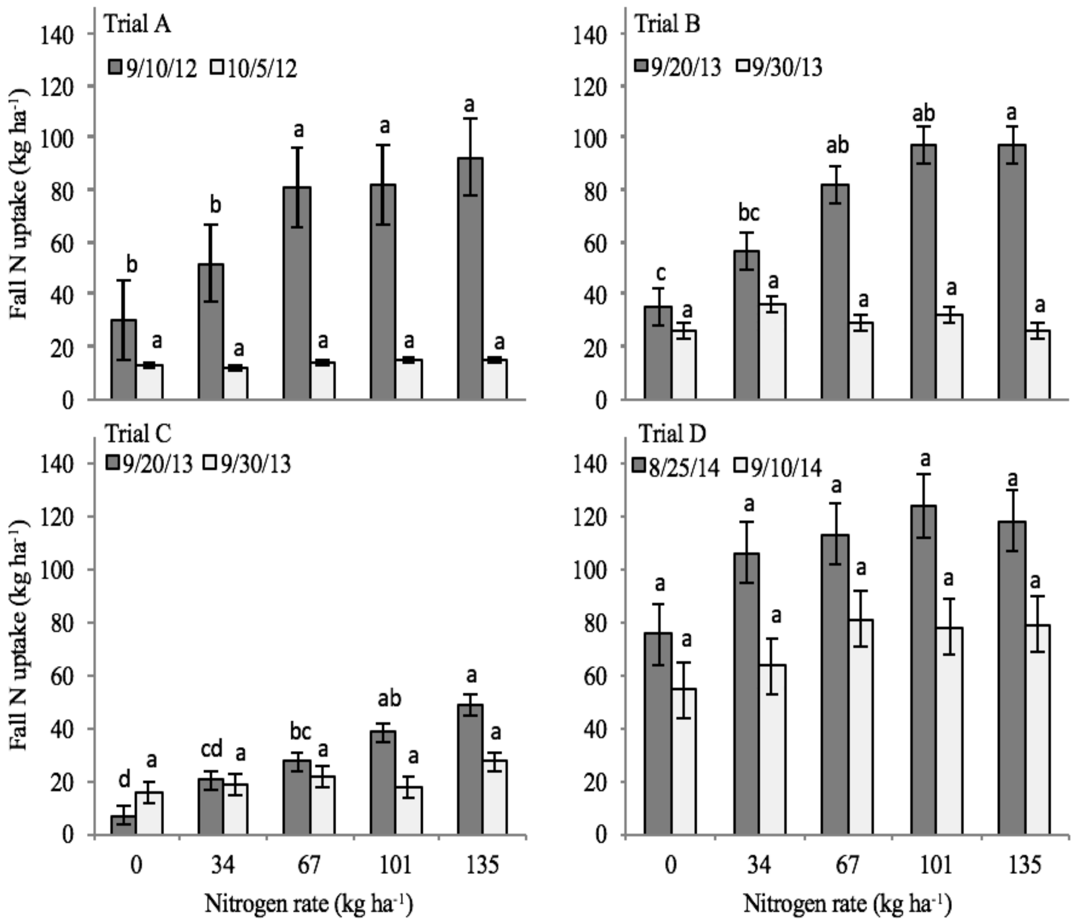

Figure 1.2. Effect of planting date and nitrogen (N) rate on triticale fall N accumulation for four trials in New York (*n* = 160). Triticale was harvested in late November just before snowfall for each trial. At three of the four locations (trials A, B, and C), there was a significant interaction between planting date and N rate. Error bars represent 1 SE, and different letters within each trial and planting date represent significant differences in biomass ($P \leq 0.05$).

As evidenced by a linear relationship between biomass and forage N uptake for each trial ($P < 0.0001$ for all trials; R^2 ranging from 0.89 to 0.95 and 0.65 to 0.83 for the trials planted before and after 20 September, respectively), N uptake was primarily a function of biomass accumulation, and biomass accumulation was dependent on both planting date and N availability. When planted before 20 September, triticale was better able to utilize available N and increased in overall growth and N uptake with increasing N availability. When planted after 20 September, N addition did not increase total biomass (Figure 1.1) or N uptake (Figure 1.2), emphasizing the need to plant early if fall N uptake of end-of-season N is the objective.

Planting Date, Nitrogen Rate and Nitrogen Uptake Efficiency

Trials planted by 20 September ranged in ANR from 18 to 48% and in NUE from 3 to 9 kg DM kg^{-1} N for the highest rate of N (135 kg N ha^{-1}), compared to 40 to 91% ANR and 2 to 14 kg DM kg^{-1} N NUE for the 34 kg N ha^{-1} rate. The NUE at the yield plateau for these planting dates ranged from 2.6 to 13.2 kg DM kg N^{-1} and ANR at the yield plateau ranged from 28 to 58% (Table 1.3). Although there were no significant differences in ANR among N rates for these planting dates, the 10 September planting date for trial A decreased in NUE from 29 kg DM kg^{-1} N at 34 kg N ha^{-1} to 10 kg DM kg^{-1} N at 134 kg N ha^{-1} ($P = 0.005$; Figure 1.3). For planting dates after 20 September, only the 30 September planting date for trial B had significant differences in ANR ($P = 0.003$) and NUE ($P = 0.008$) among treatments, ranging from slightly negative to 28% ANR and 3 kg DM kg^{-1} N NUE for the 135 and 34 kg N ha^{-1} treatments, respectively.

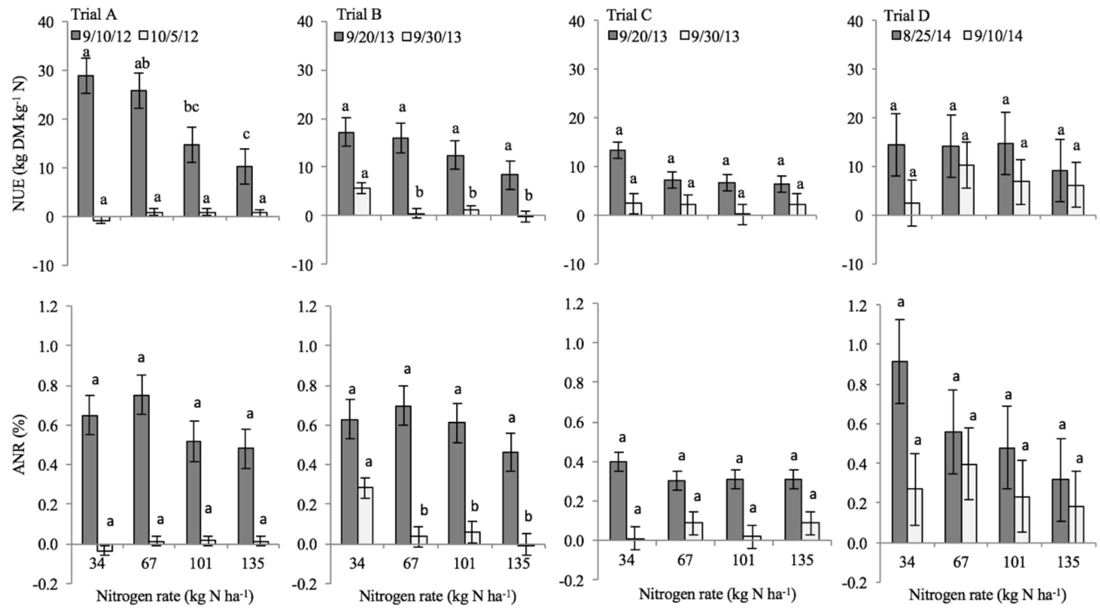

Figure 1.3. Effect of planting date and nitrogen (N) rate on nitrogen use efficiency (NUE; n = 160) and apparent nitrogen recovery (ANR; n = 160) of triticale receiving N in the fall at planting and assessed for N uptake efficiency in November, just prior to snowfall. Only for trial A was there a significant interaction between planting date and N rate. Errors bars represent 1 SE, and different letters within each trial and planting date represent significant differences in biomass ($P \leq 0.05$).

For these planting dates, NUE at the yield plateau ranged from 0.2 to 6.4 kg DM kg N^{-1}, and NUE at the yield plateau ranged from 0.2 to 27% (Table 1.3). Trials A and C had no significant differences among N rates for planting dates after 20 September (*P* = 0.4 and 0.8 for trials A and C, respectively) and ranged from -4 to 9% ANR. Due to the lack of differences in ANR and NUE among N rates for the earlier planting dates, only trial A expressed an interaction between planting date and N rate. Planting earlier resulted in increased ANR and NUE as compared to the later planting dates ($P < 0.002$ for all trials, Figure 1.3), suggesting that the increased biomass due to earlier planting impacted NUE more than the actual N rate within a specific planting date.

Differences in ANR and NUE among locations, as found in our study, were also observed in a study involving Kentucky bluegrass (*Poa pratensis* L.), smooth bromegrass (*Bromus inermis* Leyss.), and orchardgrass (*Dactylis glomerata* L.) by Zemenchik and Albrecht (2002). Although not significant, Zemenchik and Albrecht (2002) noted a range in ANR and NUE across two locations, suggesting that soil type and climate can impact ANR and NUE. Average ANR values for the grasses harvested between June and September in Zemenchik and Albrecht (2002) ranged from 17 to 50%, and NUE ranged from 9 to 28 kg DM kg^{-1} N, depending on the species. Because measurements in this study were taken during the summer and early fall months and species were different, they cannot be directly compared to those of triticale planted in the fall following corn silage harvest, but the trends are consistent among both studies.

Our findings suggest that N recovery in the fall is dependent on biomass accumulation, which, in the Northeast, is directly related to how early the crop is planted. Biomass response to N addition with planting before September 20 suggests that fall application of N could benefit fall growth, while for later planting dates fall N uptake will likely be very low. While this could indicate an environmentally safer and more productive window for fall manure applications, additional research is needed to extend these findings to fall-applied manure.

CONCLUSIONS

Winter cereals like triticale grown as double or cover crops have the potential to take up residual N as well as additional N applied at or shortly after planting. Our results show that triticale planted prior to 20 September on average accumulated 70 kg N ha^{-1} with 3.3 Mg DM ha^{-1} fall growth as compared to an average of 21 kg N ha^{-1} and 0.6 Mg DM ha^{-1} fall growth if planted after 20 September. Nitrogen addition (or greater N availability) did not increase biomass production when the triticale was planted late (after 20 September). However, when planted earlier, triticale growth increased with N availability, showing the benefits of early seeding for utilizing end-of-season N or newly applied (manure) N. We conclude that planting winter cereals like triticale early in the fall can sequester N that could potentially be lost in the humid Northeast and provide dairy farmers with an additional opportunity to apply manure while reducing the risk of N loss to the environment. More research is needed to determine more precise planting windows for optimal N utilization by triticale across the entire Northeast, especially for fields with a recent manure history, in addition to determining an upper limit to the amount of manure that can be applied in the fall if a winter cereal double crop is present.

ACKNOWLEDGEMENTS

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CHAPTER 2: SPRING NITROGEN MANAGEMENT IS IMPORTANT FOR TRITICALE FORAGE YIELD AND QUALITY[1]

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ABSTRACT

Including triticale (x *Triticosecale* Wittmack) in forage rotations can provide economic and environmental benefits if optimally managed. We determined the impact of planting date, fall nitrogen (N) availability, and spring N application on triticale dry matter (DM) forage yield and crude protein (CP) content. Three trials were conducted in New York from 2012 to 2014, each with two planting dates, five fall N rates (0, 34, 67, 101, 135 kg N ha^{-1}), and five spring N rates (0, 34, 67, 101, 135 kg N ha^{-1}) using a randomized complete block split-split-plot design in four replications. Plants were sampled for biomass in November before frost and harvested in May at flag-leaf stage. Across sites, a small amount of fall N (34 kg N ha^{-1}) increased spring yield in the zero-N plots from 1.9 to 3.7 Mg DM ha^{-1} when seeded by 20 September. For later seedings, fall N did not benefit yield (2.7 Mg DM ha^{-1} average

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Lyons, S.E., Q.M. Ketterings, G. Godwin, J.H. Cherney, K.J. Czymmek, and T. Kilcer. 2018. Spring nitrogen management is important for triticale forage yield and quality. Agron. J. 110:1-8. doi:10/2134/agronj2018.01.0041

yield). Forage CP was 10.7% of DM when 135 kg N ha^{-1} was fall-applied to sites planted by 20 September, versus 9.4% averaged across all other N rates and planting dates. While earlier planting increased spring yields, the most economic rate of N (MERN) and yield at the MERN in the spring were not impacted by fall N or planting date. Planting after 20 September increased CP at the MERN by about 1%. While fall management had some influence on spring performance, spring N management was most critical for achieving optimal yield and quality.

INTRODUCTION

Field crop production in New York is centered around dairy forage, which commonly includes one main crop per growing season due to the long winters and relatively short growing seasons of the Northeast. Rotations typically consist of corn (*Zea mays* L.) for 3 to 4 yr followed by alfalfa (*Medicago sativa* L.) or an alfalfa-grass mixture for 3 to 4 yr. During the corn years, the ground is often left bare over the winter months due to time and financial constraints of planting a cover crop. However, in recent years cover crop use among dairy producers in New York has grown (Long et al., 2013) as more producers recognize that planting a cool-season crop following corn harvest has many long-term benefits, including lowered risk of soil erosion, enhanced rotation diversity, increased soil organic matter, weed suppression, and reduced nutrient loss (Dabney et al., 2001; Feyereisen et al., 2006; Mirsky et al., 2011; Long et al., 2013; Ketterings et al., 2015b). While the environmental benefits of overwintering cover crops have been established and farmers recognize the importance of cover crops for soil health, more dairy farmers now recognize the potential benefits of harvesting these overwintering cover crops for expansion of the feed supply (Ketterings et al., 2015a).

Triticale, a hybrid of wheat (*Triticum aestivum* L.) and rye (*Secale cereal* L.), is a winter hardy cereal that is a good option for double cropping in the Northeast, with planting windows through mid-November and harvest at flag-leaf stage in mid to late May. Proper management of the winter cereal is essential for optimal performance in the spring. Due to the long winters in the Northeast, the spring growing period prior to harvest for triticale is typically just 3 to 4 wk, making the management of this forage crop unique as compared to those grown in other regions. Ketterings et al. (2015a) surveyed farmers who grew winter cereals for forage in New York, and found that 79% applied fertilizer N at dormancy break to achieve higher yields. Statewide N rate trials also found that triticale and rye needed additional N at dormancy break to achieve optimal yields (Ketterings et al., 2015a).

A study on triticale response to N applied in mid-March in Iowa by Gibson et al. (2007) showed that N uptake by triticale following corn and soybeans increased with additional applied N, and that yields of both triticale grain and forage were optimized with a small N application (33 kg N ha^{-1}). This study had only one planting date per trial, and no additional N was applied in the fall. It is well known that inorganic soil N not taken up by a living crop is lost over the winter months in the Northeast (Ketterings et al., 2003; Sadeghpour et al., 2017), so knowing whether any fall N uptake impacted performance in the study by Gibson et al. (2007) would have been helpful to determine if the same seasonal challenges were experienced as in the Northeast. Additionally, a small amount of supplied N (33 kg N ha^{-1}) may not be sufficient for optimum forage yields in the Northeast as was determined in the Midwest. In trials in New York, planting before September 20 resulted in increased biomass, N uptake, and N use efficiency in the fall (Lyons et al., 2017). However, it is unclear how fall planting and fall N availability impact performance of the winter cereals in the spring. The objectives of this study are to determine if fall N application compensates for spring N needs, and if planting date influences the effect of fall N on spring N needs, yield, or quality.

MATERIALS AND METHODS

Locations and Experimental Design

Three triticale field trials were conducted in New York from 2012 to 2014, including two trials at the Valatie Research Farm in Columbia county, NY (trial A, 2012 to 2013; trial B, 2013 to 2014) and one trial at the Pullyen-Tailby Farm managed by the Cornell University Agricultural Experiment Station in Tompkins county, NY (trial C, 2013 to 2014). The field used for trial A was idle in the summer prior to fall seeding, following triticale harvest. The field with trial B was an abandoned grass field prior to fall seeding while trial C was planted on a field that had been harvested for sweet corn. Fall N uptake and biomass response to fall N application were presented in Lyons et al. (2017). The fourth trial that was included in Lyons et al. (2017) was destroyed by deer in the spring of the following year and is hence not included in the current set of data. The soil at trials A and B was an outwash-derived Hoosic gravelly loam (sandy-skeletal, mixed, mesic Typic Dystrudepts), while trial C had a Hudson silty clay loam (fine, illitic, mesic Glossaquic Hapludalfs). Weather data were collected at the Copake weather station in Columbia county, approximately 50 km from the Valatie Research Farm, and the Cornell University research station in Tompkins county, approximately 5 km from the Pullyen-Tailby Farm. There was more precipitation than normal for trial A in September (178 mm vs. normal 98 mm) and May (192 mm vs. normal 110 mm), and less than normal precipitation in January for trial A (16 mm vs. normal 81 mm) and May for trial B (60 mm vs. normal 110 mm), although rainfall information for some days was missing for trials A and B (Table 2.1). For all other months, temperature and monthly precipitation were consistent with long-term averages.

Table 2.1. Monthly precipitation and temperature for three triticale trials in New York conducted from 2012 to 2014. Data were obtained from within-county weather stations (Northeast Regional Climate Center, 2016). The average monthly temperature was determined from calculated daily averages [(maximum daily temperature – minimum daily temperature)/2].

Trial	Year	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Total monthly precipitation		-----------------------------				mm		-----------------------------------			
A	2012-13	71	178	81	38	91	16	61	60	41	192
	Normal†	94	98	96	78	85	81	61	86	92	110
B	2013-14	89	84	28	33	116	68	59	24	71	60
	Normal†	94	98	96	78	85	81	61	86	92	110
C	2013-14	133	96	68	92	57	41	50	77	62	113
	Normal†	86	98	82	79	63	54	52	65	84	82
Average monthly temperature		-----------------------------				°C		-----------------------------------			
A	2012-13	22.1	15.9	11.8	4.5	0.6	-4.6	-2.7	0.6	8.2	14.8
	Normal†	20.6	15.8	9.4	3.8	-2.2	-5.3	-4.0	1.2	7.5	13.7
B	2013-14	18.5	16.2	11.9	5.6	-0.9	-6.5	-3.8	-3.9	8.3	15.7
	Normal†	20.6	15.8	9.4	3.8	-2.2	-5.3	-4.0	1.2	7.5	13.7
C	2013-14	18.7	14.3	10.8	2.1	-2.4	-7.9	-7.6	-4.2	6.3	13.6
	Normal†	19.6	15.2	9.1	3.8	-2.1	-5.2	-4.7	0.2	6.6	13.0

†Normal values are averages of monthly values from 1982 to 2014 for trials A and B and from 1982 to 2015 for trial C.

Trials were organized in a randomized complete split-split plot design with four replications. Planting date was the whole plot (two planting dates per trial). Subplots were five N rates applied at planting in the fall (0, 34, 67, 101, and 135 kg N ha^{-1}), and sub-subplots were five N rates applied at dormancy break in the spring (0, 34, 67, 101, and 135 kg N ha^{-1}). Spring fertilizer was applied on 29 March, 7 April, and 3 April for trials A, B, and C, respectively. Fertilizer N was broadcast as AGROTAIN®ULTRA-treated urea (Koch Agronomic Services, LLC, Wichita, KS). Four soil composites per trial (20 cores for each replicate, 0- to 20-cm depth) were taken prior to fertilization at planting to determine baseline soil fertility parameters (Table 2.2).

Table 2.2. Baseline soil characteristics for three triticale trials in New York conducted from 2012 to 2014. Values are averages of four soil samples (0- to 20-cm depth) within each field. The Cornell Morgan soil test method (Morgan, 1941) was used for all nutrients, and soil organic matter (SOM) was determined by loss on ignition at 500°C (Storer, 1984). The Morgan soil test interpretations are: L, low; M, medium; H, high; and VH, very high.

Tria	Planting date	pH	SOM	NO_3	P	K	Mg	Ca	Mn	Zn
			g kg^{-1}	-------------------------------		mg kg^{-1}	-------------------------------			
A†	9/10/12	6.5	33	na‡	6.8 (H)	79 (H)	145 (VH)	1178	5.9	0.3 (M)
A†	10/5/12	6.5	33	na‡	6.8 (H)	79 (H)	145 (VH)	1178	5.9	0.3 (M)
B	9/20/13	6.6	26	na‡	5.9 (H)	89 (H)	134 (VH)	1105	19.1	0.2 (L)
B	9/30/13	6.6	25	na‡	4.6 (H)	91 (H)	129 (VH)	952	17.9	1.0 (H)
C	9/19/13	5.7	22	1.2	13.8 (H)	134 (VH)	105 (VH)	819	17.1	0.4 (M)
C	10/2/13	5.6	20	1.0	13.3 (H)	134 (VH)	106 (VH)	811	20.0	0.4 (M)

†Only one set of soil analyses done for both planting dates.
‡na, not applicable.

Planting and Harvest

Planting dates were 10 September and 5 October for trial A, 20 and 30 September for trial B, and 19 September and 2 October for trial C. Triticale (Trical 815, King's AgriSeeds Inc., Ronks, PA) was drilled at a 2.54-cm depth at 135 kg ha^{-1} with 19.5-cm row spacing. Plots receiving fall N were 0.005 ha each split into 0.001 ha plots for spring N applications. The biomass sampling method in the fall was described in Lyons et al. (2017). In the spring, triticale was harvested for forage at Feekes stage 9 (Zadoks et al., 1974), when the flag-leaf was present, but seed heads had not yet emerged. Harvest dates were 14 May, 21 May, and 19 May for trials A, B, and C, respectively. Yield was determined by harvesting 3-m by 5-m row plots with a Carter Harvester (Carter Mfg. Co., Inc., Brookston, IN) at a 10-cm cutting height. Trial B had 24 plots that were severely impacted by snow mold, and data for those plots were eliminated from the study. Forage subsamples were dried at 50°C and DM content was determined.

Soil and Forage Analysis

Dried triticale biomass was ground to pass a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) and submitted to a laboratory (Brookside Laboratories Inc., New Bremen, OH) for total C and N determination via combustion analysis using an element analyzer (Vario EL cube, Elementar, Germany). Total forage N was multiplied by 6.25 to determine CP concentration following the AACC standard protocol (AACC, 1999, Method 46-10.01). Fall biomass and forage N were reported in Lyons et al. (2017).

For trial C, pre-sidedress soil nitrate tests (0- to 20-cm depth) using the Morgan extraction (Morgan, 1941) and a discrete analyzer (EasyChem Plus, Chinchilla Scientific, LLC, Oak Brook, IL) were used to determine soil nitrate prior to planting and fertilization. Unfortunately, such nitrate analyses were not done for trials A and B. However, low nitrate values are expected at both locations as the field was idle for trial A and a poor quality grass for trial B.

At dormancy break, soil samples were taken at all trials (composite of 10 samples per plot; 0- to 20-cm depth). Soil composites were dried at 50°C and ground to pass through a 2-mm screen before submitting for baseline soil fertility analysis (Analytical Laboratory and Maine Soil Testing Service, Orono, ME) (Table 2.2). Soil pH was measured in a 1:1 (w/v) water extract, and soil organic matter (SOM) was determined by loss-on-ignition through exposure to 500°C for 2 h (Storer, 1984). The Cornell Morgan soil test was used to extract P, K, Mg, Ca, Mn, and Zn by shaking dried samples in a 1:5 (v/v) ratio for 15 min in Morgan solution (1 M sodium acetate buffered at pH 4.8; Morgan, 1941). The extracts were filtered through a Whatman No. 2 equivalent filter paper following procedures outlined in NEC-1012 (Northeast Coordinating Committee for Soil Testing, 2011). The filtered extracts were analyzed for K, Mg, Ca, Mn and Zn using an inductively coupled plasma atomic emission spectrometer (ICP-AES, JY70 Type II, Jobin Yvon, Edison, NJ). Phosphorus was determined colorimetrically using the ammonium molybdate-ascorbic acid method (Knudsen and Beegle, 1988) with a Lachat QuikChem® 8000 flow injection analyzer (Lachat Instruments, Milwaukee, WI).

Soil pH ranged from 5.6 to 6.6, acceptable for optimal triticale production. Soil organic matter ranged from 20 to 33 g kg^{-1}. Soil test P and Mg were high for all trials, while K was high for the Valatie trials and very high for the Pullyen-Tailby trial according to soil fertility interpretations of Cornell University (Cornell Cooperative Extension, 2016). Zinc was classified as medium to low in the three trials based on soil test interpretations for field crops in New York (Cornell Cooperative Extension, 2017). However, winter cereals have a relatively low sensitivity to soil zinc deficiency (Clark, 1990; Viets et al., 1954) and no Zn deficiencies were visible.

Statistical Analysis

There was a significant effect of location on both yield and CP. Thus, each trial was analyzed individually as a split-split-plot design using PROC MIXED of SAS with Tukey correction for multiple comparisons (SAS Institute, 1999). The three treatments (planting date, fall N application, spring N application) were treated as fixed effects and replication was the random effect. All interactions among treatments were tested. The ratio of fall and spring growth was determined using the fall biomass data reported in Lyons et al. (2017). Significance was determined when $P \leq 0.05$.

The MERN for the spring was determined for each trial at each fall N rate using a quadratic plateau model:

$$\text{Yield plateau (kg N ha}^{-1}\text{)} = -b/2c \qquad [2.1]$$

and the MERN:

$$\text{MERN (kg N ha}^{-1}) = (\text{N cost} - b(\text{crop value}))/2c(\text{crop value}) \qquad [2.2]$$

where b is the linear coefficient, c is the quadratic coefficient, N cost is \$1.54 kg^{-1}, and crop value is \$275.00 Mg^{-1} DM.

Spring N use efficiency (NUE) and apparent N recovery (ANR) were calculated for each fall N rate within each trial. The NUE represents the increase in DM yield per kg N added (Eq. 2.3) while ANR indicates the N removal in harvest per kg N applied (Eq. 2.4) (Ketterings et al., 2007):

$$NUE\ (kg\ DM\ kg^{-1}\ N) = (DM\ at\ N_{rate} - DM\ at\ control)/N\ applied \qquad [2.3]$$

$$ANR\ (\%) = (N\ at\ N_{rate} - N\ at\ control)/(N\ applied) \times 100 \qquad [2.4]$$

Fall NUE and ANR were reported in Lyons et al. (2017).

RESULTS AND DISCUSSION

Planting Date, Fall Nitrogen, and Spring Performance

The impact of fall N application on spring yield when no spring N was applied varied among the three trials (Figure 2.1). For trial A, fall N applications of at least 67 kg N ha^{-1} increased spring yield from 2.8 Mg DM ha^{-1} at < 67 kg N ha^{-1} to 4.7 Mg DM ha^{-1} at ≥ 67 kg N ha^{-1} where planting had taken place on 10 September ($P < 0.0001$). For the plots planted 5 October, there was no effect of fall N on spring yield ($P = 0.7$), and yields averaged 2.7 Mg DM ha^{-1}.

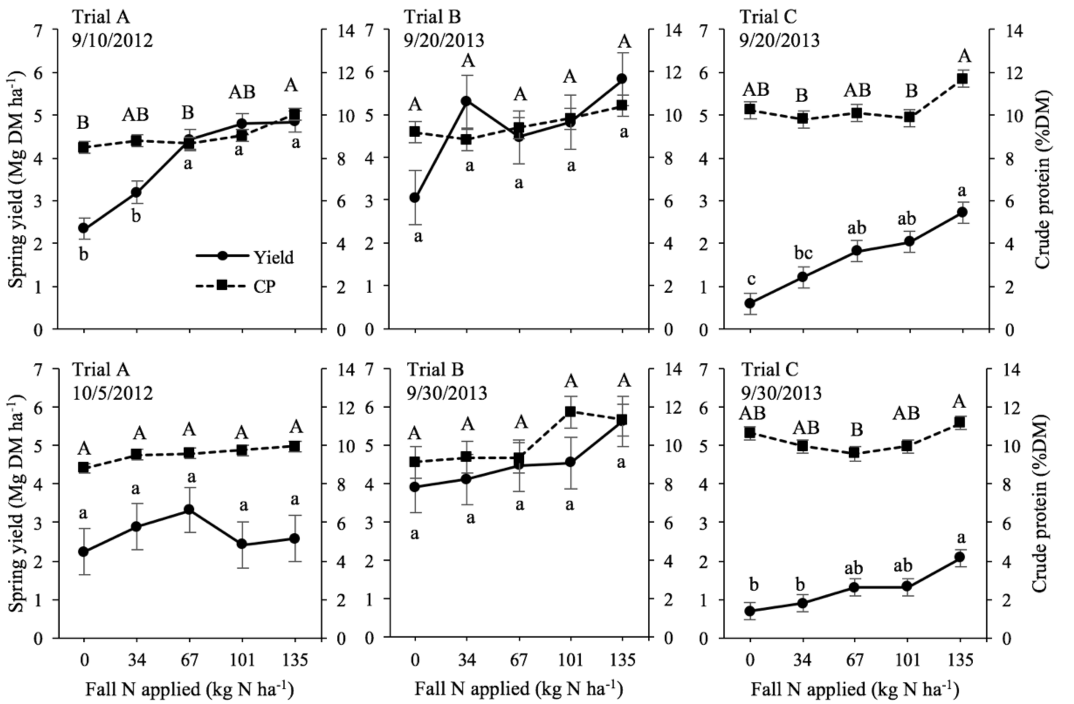

Figure 2.1. Effect of fall N application on spring triticale yield and crude protein concentrations at two planting dates with no spring N applied for three trials in NY (*n* = 600). Fall N was applied at planting and triticale was harvested at flag-leaf stage in May of each year. Values are least squares means and error bars represent 1 SE. Dates are when the triticale was planted in the fall. Different letters indicate significant differences ($P \leq 0.05$). Upper-case letters are for CP data and lower-case letters are for yield data.

In trial B, there was no effect of fall N on spring yield for either planting date when no spring N was applied (P = 0.08 and 0.45 for the 20 and 30 September planting dates, respectively). Yields averaged 4.7 and 4.5 Mg DM ha^{-1} for the 20 and 30 September planting dates, respectively. Fall N increased spring yield for both planting dates in trial C when no spring N was applied (P = 0.0003 and 0.0055 for 19 September and 2 October planting dates, respectively). Spring yield increased from 0.6 (0 kg N ha^{-1} fall N) to 2.7 Mg DM ha^{-1} (135 kg N ha^{-1} fall N), a 3.5-fold increase, for the 19 September planting date, and from 0.7 (0 kg N ha^{-1} fall N) to 2.1 Mg DM ha^{-1} (135 kg N ha^{-1} fall N), a twofold increase, for the 2 October planting date. Differences among trials may be partially due to weather; while temperatures were approximately normal for all trials, trial A had more rain than normal in September and May, trial B had less rain than normal in October, November, and March, and trial C had normal precipitation over the course of the study (Table 2.1). Averaged across sites, plots planted before 20 September had increased yield when a small amount of fall N was applied (34 kg N ha^{-1}), from 1.9 Mg DM ha^{-1} to 3.7 Mg DM ha^{-1}. However, fall N had less of an impact on spring yield across sites if planting took place after 20 September. These results are similar to those reported by Nance et al. (2007) in a study on triticale grain production in Iowa where the triticale was fertilized with different rates of N at planting (after 20 September) following either corn or soybean; in their study, Nance et al. (2007) found that only the plots following corn at one location had a yield increase with a small amount of N applied in the fall (33 kg N ha^{-1}), with no differences in yield among the other treatments and locations.

While fall N application had some influence on spring yield where no spring N was applied, it had much less impact on spring CP (Figure 2.1). For trial A at the 10 September planting date, CP was higher for the 135 kg N ha^{-1} fall N rate (10.0% CP) than the 0 and 67 kg N ha^{-1} fall N rates (8.5 and 8.7% CP, respectively) ($P = 0.01$), but there were no other differences among treatments. There were no differences in CP among fall N rates ($P = 0.08$), averaging 9.5% CP, for the 5 October planting date. Trial B had no differences in CP among fall N rates for either planting date, averaging 9.5 and 10.2% CP for the 20 and 30 September planting dates, respectively. While trial C showed differences in CP among some of the fall N rates ($P = 0.03$ and $P = 0.04$ for the 19 September and 2 October planting dates, respectively), the 0 and 135 kg N ha^{-1} treatments were not different in CP for either planting date.

These results indicate that fall uptake of N is not as influential as spring N application is on forage protein content, specifying the need for proper spring fertilization management for optimal nutritive performance. Although triticale harvested as forage in the Northeast has a very short (3 to 4 wk) growing period and will require different management from cereals grown in other regions for other purposes, our results are similar to findings of a winter wheat study by Romero et al. (2017) with surface-applied urea with a urease inhibitor (NBPT) in the fall, winter, and spring. Romero et al. (2017) reported that while more N was recovered when a urease inhibitor was used, grain protein was higher when the fertilizer was applied in the spring as compared to applications of N in the fall or winter.

Planting Date, Fall and Spring Nitrogen, and Spring Performance

There was an interaction between planting date and fall N rate on spring yield in trial A ($P < 0.0001$) (Figure 2.2). Across all spring N rates, fall N application increased spring yield for the 10 September planting (from 3.7 Mg DM ha^{-1} for the 0 kg N ha^{-1} fall N rate to 5.8 Mg DM ha^{-1} for the 135 kg N ha^{-1} fall N rate) but did not result in a yield increase for the 5 October planting (averaging 3.8 Mg DM ha^{-1}). There was a main effect of spring N rate on spring yield for trial A as well ($P < 0.0001$), increasing from 3.3 Mg DM ha^{-1} for the 0 kg N ha^{-1} spring N rate to 5.0 Mg DM ha^{-1} for the 135 kg N ha^{-1} spring N rate across all fall N rates and planting dates.

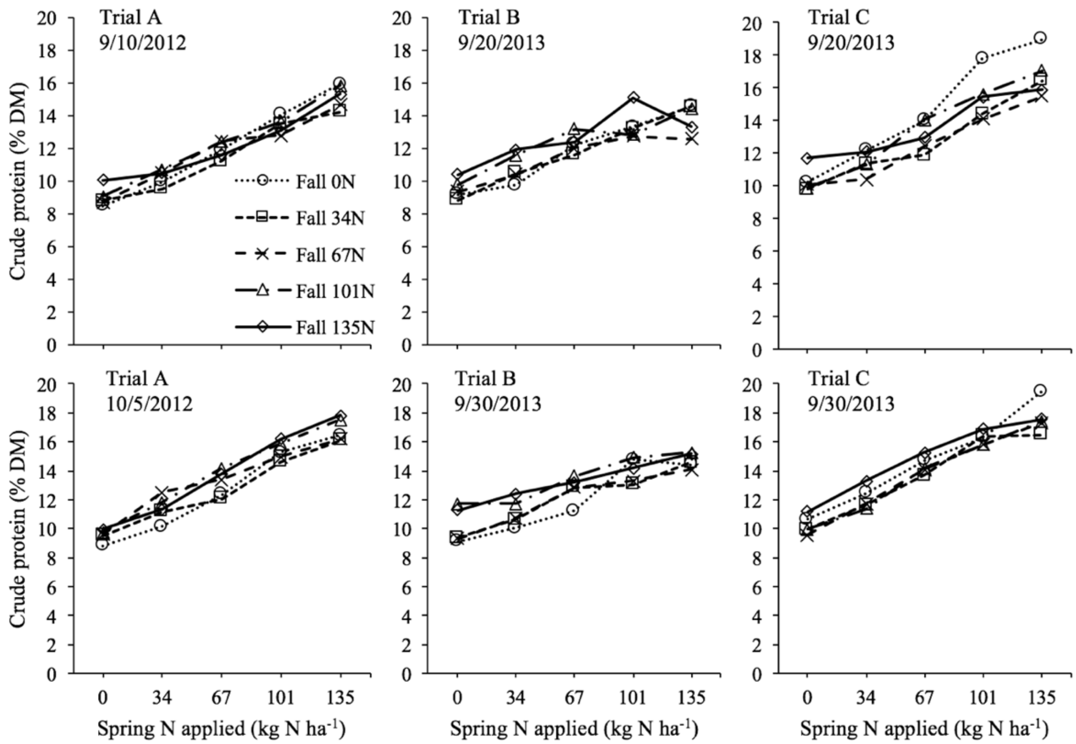

Figure 2.2. Triticale spring dry matter yield response to fall and spring applied N at two planting dates for three trials in NY (n = 600). Fall N was applied at planting, and spring N was applied at green-up in the spring. Triticale was harvested at flag-leaf stage in May of each year. There was an interaction between planting and fall N on spring yield for trial A ($P < 0.0001$). All other main effects of each treatment were also significant for each trial ($P \leq 0.05$). Dates indicate fall planting date.

For trials B and C, there were no interaction effects among the treatments on yield but all main effects (fall N, spring N, and planting date) were significant ($P < 0.01$ for all). Fall N, spring N, and earlier planting resulted in an increase in spring yield. Average yields for the 0, 34, 67, 101, and 135 kg N ha^{-1} spring treatments were 4.6, 5.4, 5.9, 6.1, and 6.0 Mg DM ha^{-1} for trial B and 1.5, 2.3, 2.6, 2.8, and 2.7 Mg DM ha^{-1} for trial C, respectively. Average yields for the 0, 34, 67, 101, and 135 kg N ha^{-1} fall treatments were 5.1, 5.4, 5.6, 5.8, and 6.3 Mg DM ha^{-1} for trial B and 1.6, 2.1, 2.7, 2.4, and 3.0 Mg DM ha^{-1} for trial C, respectively. Average yields for the first and second planting dates were 5.8 and 5.5 Mg DM ha^{-1} for trial B and 2.6 and 2.1 Mg DM ha^{-1} for trial C.

Spring CP behaved similarly among the three trials. While interactions were not significant, fall N, spring N, and planting date all impacted spring CP for each trial ($P < 0.01$) (Figure 2.3). All later planting dates had slightly higher CP than earlier planted plots (averaging 12.5% and 13.4% CP for the first and second planting dates, respectively). Spring N additions increased CP (averaging 9.8, 11.2, 13.0, 14.7, and 15.9% CP for the 0, 34, 67, 101, and 135 kg N ha^{-1} treatments at green-up, respectively), while fall N had minimal impact on spring CP (averaging 13.1, 12.5, 12.5, 13.2, and 13.4% CP for 0, 34, 67, 101, and 135 kg N ha^{-1} treatments at planting, respectively). These results show that while timing of planting and fall N availability could influence spring performance, N management in the spring is essential for optimal yield and quality of winter cereals grown for forage.

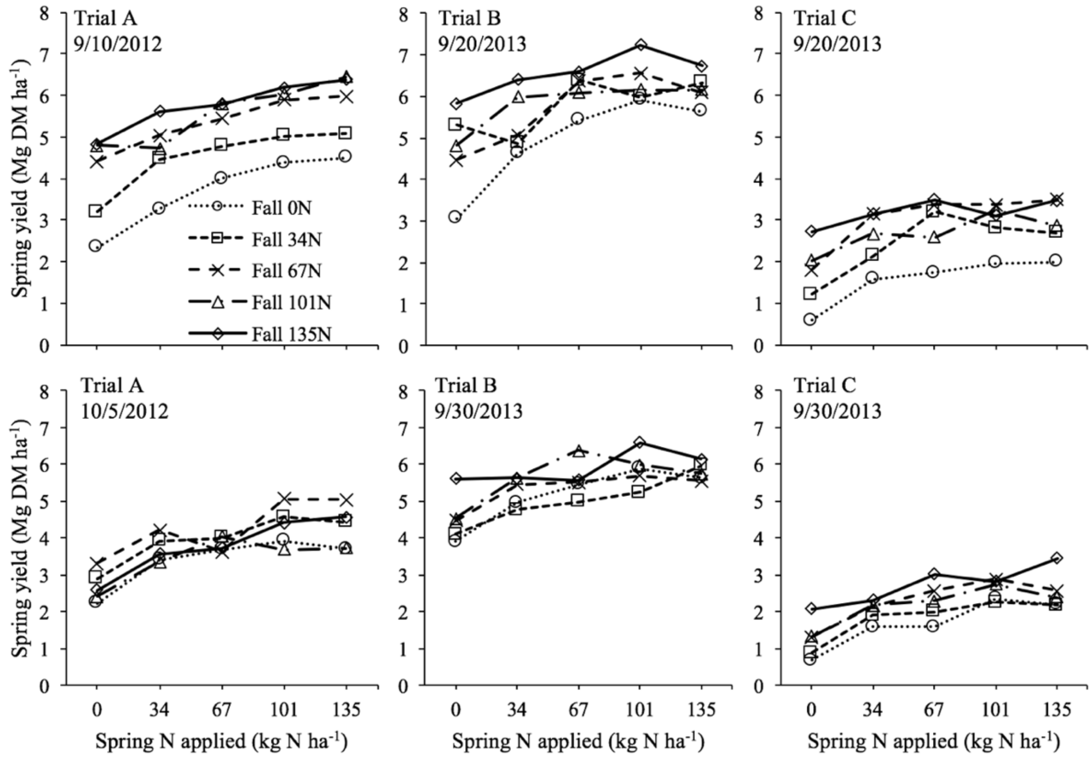

Figure 2.3. Triticale spring crude protein (CP, % of DM) response to fall and spring applied N at two planting dates for three trials in NY (n = 600). Fall N was applied at planting, and spring N was applied at green-up in the spring. Triticale was harvested at flag-leaf stage in May of each year and analyzed for total N content. Fall N, spring N, and planting date significantly impacted spring CP for all trials ($P \leq 0.05$). Dates indicate fall planting date.

Planting Date, Fall and Spring Nitrogen, and Spring Nitrogen Uptake Efficiency

Each trial behaved differently in ANR and NUE. For trial A, there was an interaction between planting date and fall N application on both measures of efficiency (P = 0.04 and P = 0.0017 for ANR and NUE, respectively). For the 10 September planting date, there was a greater influence of fall N on both ANR and NUE than when planting was done on 5 October. At the 10 September planting date, ANR ranged from -18 to 109% across the spring N rates for the 34 kg N ha^{-1} fall N rate and 43 to 74% for the 135 kg N ha^{-1} fall N rate, as compared to the 5 October planting date with 42 to 71% and 42 to 66% for the 34 and 135 kg N ha^{-1} fall N rates, respectively. The NUE for the 10 September planting date ranged from -20 to 50 kg DM kg N^{-1} when 34 kg N ha^{-1} was applied in the fall, and 4 to 18 kg DM kg N^{-1} when 135 kg N ha^{-1} was applied in the fall. For the 5 October planting date, NUE ranged from 21 to 26 kg DM kg N^{-1} and 8 to 14 kg DM kg N^{-1} when 34 and 135 kg N ha^{-1} was applied in the fall, respectively.

Trial B had an interaction between spring and fall N on both ANR (P = 0.0001) and NUE (P = 0.0148), and a main effect of planting date on ANR (P = 0.04). There was a greater difference in ANR and NUE when 34 kg N ha^{-1} was applied than when 135 kg N ha^{-1} was applied in the spring. The different fall N rates led to a range in ANR from 1 to 147% and NUE from 6 to 59 kg DM kg N^{-1} at the 34 kg N ha^{-1} spring N treatment. ANR ranged from 35 to 54% and NUE from 9 to 17 kg DM kg N^{-1} at the 135 kg N ha^{-1} spring N treatment. A later planting date decreased ANR from 64% to 52% for the 10 September and 5 October dates, respectively.

Trial C only had significant main effects of fall and spring N on ANR (P = 0.0001 and 0.02 for fall and spring N, respectively) and NUE (P < 0.0001 for both fall and spring N). Spring N addition decreased spring ANR (from 53 to 36% for the 34 and 135 kg N ha^{-1}, respectively) and NUE (from 24 to 9 DM kg N^{-1} for the 34 and 135 kg N ha^{-1}, respectively). Fall N addition increased spring ANR (from 23 to 66% for the 34 and 135 kg N ha^{-1}, respectively) and NUE (from 24 to 23 DM kg N^{-1} for the 34 and 135 kg spring N ha^{-1}, respectively).

Fall Management and Spring MERN

Although fall N and planting date did impact spring triticale yield and protein, neither fall N nor planting date impacted spring MERN or yield at the MERN in any of the three trials (P > 0.1 for all) (Table 2.3). In addition, there was no impact of fall N on spring CP at the MERN, although planting date did have an effect (P = 0.02); the later planting dates had slightly higher spring CP at the MERN (14.7% CP) than the earlier planting dates (13.4% CP). There was also a difference in ANR at the MERN between the 0 and 135 kg fall N ha^{-1} treatments (42% and 74%, respectively) (P = 0.02). The greater ANR with fall N application may be due to increased biomass in the fall from N application if planted early (Lyons et al., 2017), potentially resulting in a more robust root system to better utilize available N in the spring. Further investigation is needed to determine whether root biomass is responsible for greater spring ANR. However, planting date had no impact on the ANR at the MERN and there were no differences in NUE at the MERN among the fall treatments (averaging 17.6 kg DM kg N^{-1}).

Table 2.3. The most economic rate of spring applied N (MERN), yield at the MERN, and crude protein (CP) at the MERN for three triticale trials planted at two timings with five rates of N applied both in the fall and the following spring. The MERNs were determined by fitting the yield response to spring N applications to a quadratic plateau model.

Trial	Planting date	Fall N	MERN	Yield at MERN	Fall:spring yield	CP at MERN	ANR at MERN	NUE at MERN
		--- kg N ha^{-1} ---		Mg DM ha^{-1}		% DM	%	kg DM kg N^{-1}
A	9/10/12	0	110	4.5	0.27	14.5	42	4.5
		34	90	5.1	0.43	12.5	48	11.5
		67	117	5.9	0.50	13.9	62	17.6
		101	na†	6.4‡	0.42	15.8‡	79‡	18.8‡
		135	112	6.3	0.41	13.9	73	21.2
A	10/5/12	0	80	3.9	0.10	13.4	49	14.0
		34	91	4.4	0.08	13.9	62	19.0
		67	0	4.3§	0.10	13.3§	82§	25.1§
		101	76	3.9	0.12	14.3	69	17.4
		135	128	4.5	0.10	17.6	68	14.7
B	9/20/13	0	94	5.8	0.23	12.9	55	15.0
		34	111	6.2	0.31	13.6	55	15.2
		67	87	6.4	0.38	11.9	67	24.5
		101	77	6.2	0.42	12.7	75	22.7
		135	78	6.9	0.36	12.9	91	31.0
B	9/30/13	0	89	5.7	0.11	12.9	52	19.6
		34	0	5.1§	0.16	12.1§	33§	15.9§
		67	73	5.7	0.12	12.3	51	21.4
		101	73	6.2	0.12	13.6	70	32.6
		135	0	6.0§	0.10	13.4§	74§	28.3§
C	9/19/13	0	84	1.9	0.15	15.8	18	1.7
		34	79	3.0	0.25	13.3	42	18.6
		67	82	3.5	0.22	13.1	53	21.5
		101	73	2.9	0.34	13.9	45	13.8
		135	55	3.2	0.35	13.2	77	33
C	10/2/13	0	100	2.2	0.21	16.8	37	10.8
		34	80	2.2	0.24	14.3	35	10.6
		67	80	2.7	0.22	14.5	54	18.2
		101	77	2.6	0.18	14.3	47	15.3
		135	0	2.7§	0.28	14.8§	69§	22.4§

†na, not applicable. Data did not fit a quadratic plateau response curve; MERN could not be determined.
‡Values represent the average of the highest N rate (134 kg N ha^{-1}).
§Values represent the average across all spring N rates.

While results suggest that elevated N availability at planting and timing of planting could increase spring yield and quality if no spring N is applied, the lack of impact of fall N management on the MERNs of spring applications suggests spring N management cannot be offset by fall N applications. Additional work is needed to verify these results.

The ability to predict spring yield at the MERN based on fall biomass accumulation can be useful for forage production systems. However, the ratios of fall biomass to spring yield at the MERN for the present study suggest that fall biomass is not an accurate predictor of spring yield. Neither fall N nor the interaction between fall N and planting date influenced the ratio of fall biomass to spring yield ($P > 0.10$ for all). Earlier planted plots had higher ratios (closer to 1) because more of the biomass was produced in the fall. Spring N management is essential regardless of how much fall biomass accumulates.

CONCLUSIONS

Winter cereals like triticale grown as forage double crops can provide additional harvestable forage for dairy producers in the Northeast in addition to providing numerous soil health and nutrient cycling benefits. Our findings suggest that if planted early (by 20 September in this study), a small amount of fall N addition (34 kg N ha^{-1}) can increase spring yield if no N is added in the spring. If planted later in the season, fall N may not benefit spring yields. Spring CP is only increased by fall N if a large amount is applied (135 kg N ha^{-1}) at an early planting and no N is applied in the spring. Regardless of fertilization, early planting can lead to some increases in spring yields. However, spring MERNs and the yield at the MERN were not influenced by fall N or planting date. Later planting date increased spring CP at the MERN by about 1%. We conclude that while an early planting date can increase spring triticale yield to some extent, fall N addition does not compensate for spring N needs.

ACKNOWLEDGEMENTS

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CHAPTER 3: NITROGEN RESPONSE MODELS FOR WINTER CEREALS GROWN FOR FORAGE[1]

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ABSTRACT

Forage double cropping can increase production, reduce erosion risk, and improve soil health. Farmer experience in the northeastern USA shows that winter cereals can, in 3-4 weeks (Feekes 9 harvest), produce high quality forage given sufficient N at dormancy break. Here we evaluate crop response models to determine the most economic rate of N (MERN) for forage winter cereals. Sixty-three on-farm N-rate trials (0, 34, 67, 101, 135 kg N ha^{-1}) were conducted in New York from 2013-2016. Trials were divided into four categories: (1) no yield response to N (group 1; 20 trials); (2) yield plateau exceeded the highest N rate (group 2; one trial); (3) the MERN was below the lowest N rate (group 3; seven trials); and (4) all other N-responsive trials (group 4; 35 trials). For group 4, three statistical models were compared (quadratic plateau, exponential, and square root plateau). Statistical, environmental, and economic criteria showed that the quadratic plateau fits the data best and had the most

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stable predictions across scenarios. The four-category analysis is effective in determining MERNs of individual trials, and the quadratic plateau is best for determining forage winter cereal MERNs and yields at MERNs for individual trials in the northeastern USA.

INTRODUCTION

Double cropping is a practice that involves growing two harvestable crops per growing season. It presents many environmental and economic advantages particularly in the northeastern USA, including increased forage production, reduced erosion risk, enhanced rotation diversity, and improved soil health (Dabney et al., 2001; Feyereisen et al., 2006; Mirsky et al., 2011; Long et al., 2013; Ketterings et al., 2015a; Ketterings et al., 2015b). In upstate New York, 3-4 years of corn silage (*Zea mays* L.) followed by an equal number of years in alfalfa/grass hay (*Medicago sativa* L.) is the most common forage rotation. During the corn years in this rotation, double cropping with winter cereals such as cereal rye (*Secale cereale* L.), winter wheat (*Triticum aestivum* L.), and triticale (x *Triticosecale* Wittm.) can provide the environmental benefits of a cover crop while also contributing additional home-grown forage to dairy farms (Ketterings et al., 2015a; 2015b). While this cropping system is a promising avenue for dairy farmers in the northeastern USA, little is known about how to best manage winter cereals as double crops, particularly in terms of N management at dormancy break, given the early and very short (3-4 weeks) growing season for such forage crops.

Statistical modeling of data from crop N response trials can be used to determine the most economic rate of N (MERN) for a given field in a specific scenario (i.e. fertilizer cost, crop value, environmental sensitivity). The MERN is obtained by equating the first derivative of the response to the price ratio of fertilizer cost to crop value and solving for N (Cerrato and Blackmer, 1990) (Table 3.1, Eq. 1).

Table 3.1. Models used for fitting yield response data and determining the most economic rates of N in the literature and for forage winter cereal N rate trials in New York.

No.	Title	Equation	Reference
		--------------------------------------Models from literature---	
1	Most economic rate of N (MERN)	$Max(pY(N) - wN)$	Bullock and Bullock (1994)
2	Quadratic	$E\{Y(N)\} = a + bN + cN^2$	Bullock and Bullock (1994)
3	Quadratic plateau	$E\{Y(N)\} = \begin{cases} a + bN + cN^2, & N < M \\ a + bM + cM^2, & N \geq M \end{cases}$	Isfan et al. (1995)
4	Linear plateau	$E\{Y(N)\} = \begin{cases} a + bN, & N < M \\ a + bM, & N \geq M \end{cases}$	Isfan et al. (1995)
5	Square root	$E\{Y(N)\} = a + bN + cN^{0.5}$	Llewelyn and Featherstone (1997)
6	Exponential (Mitscherlich)	$E\{Y(N)\} = q(1 - e^{-r(N+s)})$	National Academy of Sciences (1961); Cerrato and Blackmer (1990)
		--Models for study---	
7.1†	Quadratic plateau	$E\{Y(N)\} = \begin{cases} bN + cN^2 + \mu + \frac{b^2}{4c}, & N < -\frac{b}{2c} \\ \mu, & N \geq -\frac{b}{2c} \end{cases}$	
7.2	MERN for quadratic plateau	$MERN = \frac{\frac{w}{p} - b}{2c}$	
8.1†	Square root plateau	$E\{Y(N)\} = \begin{cases} bN + cN^{0.5} + \mu + \frac{c^2}{4b}, & N < \frac{c^2}{4b^2} \\ \mu, & N \geq \frac{c^2}{4b^2} \end{cases}$	
8.2	MERN for square root plateau	$MERN = \frac{c^2}{4(\frac{w}{p} - b)^2}$	
9.1†	Exponential (Mitscherlich)	$E\{Y(N)\} = \mu[1 - e^{-4(N+s)}$	
9.2	MERN for exponential	$MERN = -\frac{1}{r}\log\left(\frac{w}{pqr}\right) - s$	
10	ANR	$ANR(\%) = \frac{Forage_{N_{MERN}} - Forage_{N_0}}{MERN} \times 100\%$	Ketterings et al. (2007)
11‡	Economic risk	$Risk(\$ha^{-1}) = E\{Y(N)\} \times p) - (MERN \times w)$	Paz et al. (1999)

Table 3.1 (Continued)

Symbol	Definition
MERN	Most economic rate of N (kg N ha^{-1})
Y(N)	Response function of N treatment
N	N treatment (kg N ha^{-1})
P	Crop value ($ Mg DM^{-1})
W	Cost of N fertilizer ($ kg N^{-1})
E{Y(N)}	Expected crop yield response to N (Mg DM ha^{-1})
A	Intercept
B	Linear coefficient
C	Quadratic or square root coefficient
M	Transition point between quadratic, linear increase and plateau
q	Potential maximum yield
r	Mitscherlich effect
s	Amount of available N in the soil (kg N ha^{-1})
μ	Maximum yield predicted by the linear plateau model (Mg DM ha^{-1})
ANR	Apparent N recovery (%)
Forage N_{MERN}	Forage N uptake at the MERN or 22 kg N ha^{-1} below or above the MERN (kg N ha^{-1})
Forage N_0	Forage N uptake at 0 kg N ha^{-1} (kg N ha^{-1})
Risk	Economic loss when choosing a model that is not the best fit for the data ($ ha^{-1})

†For equations 7.1, 8.1, and 9.1, the intercept is the average value of the yield at the 0 kg N ha^{-1} treatment, and –b/2c was constrained to equal μ.

‡Expected yield was calculated with the selected model at the chosen "incorrect" MERN, and MERN was calculated by the chosen "incorrect" model.

Crop response to N fertilizer is commonly estimated using limiting nutrient response functions or polynomial functional forms as these functions possess mathematically tractable properties and provide ease of estimation (Martinez and Albiac, 2006). The five statistical models commonly used to analyze N rate studies are all deterministic yield response functions, including the quadratic (Eq. 2), quadratic plateau (Eq. 3), linear plateau (Eq. 4), square root plateau (Eq. 5), and exponential (Mitscherlich) (Eq. 6) models (Table 3.1). Plateau functions can be useful as they reflect an increase in yield up to a certain level beyond which additional fertilization has little to no effect on yield (Cerrato and Blackmer, 1990; Bullock and Bullock, 1994; Roberts et al., 2002; Alivelu et al., 2003; McSwiney and Robertson, 2005; Gagnon and Ziadi, 2010). Stochastic functions have been used to account for year to year variation across trials (Brorsen and Richter, 2012; Boyer et al., 2013).

The quadratic model, frequently used for estimating crop yield response in the literature (Cerrato and Blackmer, 1990; Bullock and Bullock, 1994; Willcutts and Overman, 1998; Bélanger et al., 2000; Tageldin and El-Gizawy, 2005; Meyer-Aurich et al., 2010; Boyer et al., 2012), assumes a diminishing return as N fertilization increases (Gagnon and Ziadi, 2010) and predicts a yield decline beyond the maximum yield potential. This model was determined to best fit corn, barley, and winter wheat grown for grain (Amon-Armah et al., 2015). While a decline in yield following N fertilization may be beneficial in preventing farmers from over-application of fertilizer, not all crops show a yield decline when N is applied beyond the optimal rate; typically excess nitrate is simply lost through leaching (Cerrato and Blackmer, 1990). In addition, a common finding was that the quadratic model overestimated yields and predicted optimum fertilization rates that were too high (Taylor and Swanson, 1973; Cerrato and Blackmer, 1990; Isfan et al., 1995; Tumusiime et al., 2011). It is suggested that due to the sharpness of the quadratic curve near the MERN, this model often predicts unattainable optimum yields and overestimates the slope of the response curve at N application rates slightly less than the MERN (Cerrato and Blackmer, 1990). This is problematic because the slope of the response is what is used for determining the MERN.

In contrast to the quadratic model, the quadratic plateau model accounts for a diminishing marginal yield response with increasing N application until a yield plateau is reached (Isfan et al., 1995). Bullock and Bullock (1994) found that the quadratic plateau fit the data without over-estimating crop yield and N requirements. Similarly, Isfan et al. (1995) found that the quadratic plateau model was more conservative in predicting optimum N rates, and therefore more economically favorable. The quadratic plateau produced lower optimum N rates than both the quadratic and linear plateau models, and for this reason was especially useful in situations where crop value was uncertain or when nitrate leaching was a risk (Isfan et al., 1995).

Like the quadratic plateau model, the linear plateau model also predicts a plateau after the maximum yield value is reached. The predicted maximum yield is the plateau yield, and the predicted MERN is the N rate at the intersection of the linear and plateau lines of the model (Waugh et al., 1973; Ihnen and Goodnight, 1985; Berck and Helfand, 1990; Alivelu et al., 2003; Paris, 1992). While numerous studies found the linear plateau model useful for estimating crop responses to N (McSwiney and Robertson, 2005; Gagnon and Ziadi, 2010), there are some drawbacks. Like the quadratic model, the linear plateau model may overestimate yield near the plateau value (Cerrato and Blackmer, 1990), resulting in MERNs that are too low. Additionally, as mentioned above, this model assumes that crop yield responds to N fertilizer linearly, which is not typically the case. In addition, the linear plateau model does not take the crop value to fertilizer cost ratio into account, thereby limiting its ability to accurately describe MERNs and yields at the MERN in certain scenarios.

The square root model is similar to the quadratic model. However, the square root model allows for a sharper curve near the maximum yield (Llewelyn and Featherstone, 1997) than the quadratic model, and thus may predict a much higher N rate to achieve maximum yields (Cerrato and Blackmer, 1990).

There are numerous forms of exponential models used for predicting crop response, all developed to fit specific scenarios. One of the most common forms is the Mitscherlich model, where the maximum yield is reached when the N application is infinite, so the exponential model has an asymptotic yield plateau. Exponential models have the potential to be useful for predicting crop yield responses, as they can accommodate plateau characteristics (Llewelyn and Featherstone, 1997). However, Cerrato and Blackmer (1990) found that the exponential model, when compared to other models, fit the deviation from regression analysis the least. Alivelu et al. (2003) compared a modified Mitscherlich's exponential model to plateau models and found that the exponential model tended to predict slightly higher maximum yields, larger MERNs due to systematic bias, and resulted in a non-normal distribution of residuals (Kolmogorov test).

Numerous studies have directly compared various yield response models to specific yield data from individual trials (Table 3.2). Every model presents various advantages and disadvantages depending on crop species, location, climate, and a number of other factors. Because of this, we cannot select the best model for winter cereals harvested for forage simply based on previous work. In particular, the short growing season in very early spring (three to four weeks from dormancy break to flag-leaf stage) makes fertility management of winter cereal grown for forage unique, requiring an independent analysis.

Table 3.2. Summary of model comparison studies for predicting yield response to fertilizer inputs for various cropping systems, including common mathematical functional forms used for response function estimation as well as criteria used for model selection.

Crop	Soil Type	Models Investigated†	Model Selected†	Criteria[1]	Study
Corn	na†	LP, QP, Q, E, SR	QP	Residual distribution Deviation from regression (Komogorov) Coefficient of determination	Cerrato and Blackmer (1990)
	Clarksdale silt loam, Muscatine silt loam	QP, Q	QP	Deviation from regression (observed-predicted) Residual distribution (Shapiro-Wilk) t-test	Bullock and Bullock (1994)
	Deep Collins, deep Memphis, Loring	na†	QP	na†	Roberts et al. (2002)
	Grenada silt loam	QSP, QP, LSP	LSP	Likelihood ratio test (and chi square)	Boyer et al. (2013)
	Various (multiple sites)	LP, Q, QP, Mitscherlich	Single model not chosen	Coefficient of determination Residual distribution	Rajsic and Weersink (2008)
	Ulysses silt loam	Q, SR, Mitscherlich-Baule, Linear von Liebig, Nonlinear von Liebig	Mitscherlich-Baule	Non-nested hypothesis Potential mis-specification costs	Llewelyn and Featherstone (1997)
	Kamouraska clay	LP, Q, QP	LP	Coefficient of determination	Gagnon and Ziadi (2010)
	Kalamazoo and Oshtemo series	na†	LP	Piecewise regression procedure	McSwiney and Robertson (2005)

Table 3.2 (Continued)

Crop	Soil Type	Models Investigated†	Model Selected†	Criteria[1]	Study
Corn, Winter Wheat, Barley	na†	L, LP, E, Q, SR, C-D, Mitscherlich-Baule	Q	Residual distribution Point ranking Coefficient of determination	Amon-Armah et al. (2015)
Rice	Red non-calcareous (Typic Ustropept)	LP, QP, Modified Mitscherlich’ s	QP	Coefficient of determination Residual distribution Deviation from regression	Alivelu et al. (2003)
Rye-Ryegrass	na†	LP, Q, Spillman-Mitscherlich	Spillman-Mitscherlich	Likelihood dominance criterion	Tumusiime et al. (2011)
Wheat	Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll)	Mitscherlich, LP	LSP	Log-likelihood value	Brorsen and Richter (2012)

† na, not applicable.

The goal of all the models is to define, as accurately as possible, the MERN and the expected yield at those rates of application. However, such analyses should incorporate not just statistical but also microeconomic, econometric, and biological components to best represent the trend and behavior of crop response to specific inputs (Amon-Armah et al., 2015). Selecting the "wrong" model for a certain cropping system can have a large impact on the predicted MERN, which could result in under- or over-application of fertilizer. It is important to accurately determine MERNs for individual fields, both for the individual farmer participating in on-farm research, and for research networks where results from individual fields are entered into a larger database to derive predictive models for N management for specific crops.

Our objectives were to: (1) evaluate a stepwise approach to categorize yield response to N data (individual trials) for consistent reporting of N response studies to individual farmers, and (2) determine the best statistical model for predicting the MERN for N-responsive trials, taking into account the impact of over- or under-prediction on yield, N use efficiency, and return on investment using various cost-to-price ratios for application of N at dormancy break of winter cereals grown for forage. Here, our focus is on a stepwise approach for analyzing N rate studies with winter forages consistently across multiple locations and years, and reporting MERNs and yield at the MERN for individual trials for use by *individual* farmers. In a follow-up article, the results of analyses of the combined database and individual field characteristics will be used to derive a recommendation system for N application at dormancy break for winter cereals grown for forage in New York.

MATERIALS AND METHODS

Locations and Experimental Design

Sixty-three on-farm trials (38 triticale, 21 cereal rye, and 4 winter wheat) were conducted in New York from 2013 to 2016, including 42 trials in 2013, 14 in 2014, six in 2015, and one in 2016. Farmers and farm advisors were invited to participate with one or more trials as part of an on-farm research network. Trials covered a wide range of soil types, including all soil management groups and soil hydrologic groups identified in New York (Ketterings et al., 2003). Winter cereal species, planting date, previous crop, and all other management decisions prior to the spring of each year were determined by the producer and were thus site-dependent.

Nitrogen rate trials, organized in a randomized complete block design with four replications of five N rates (0, 34, 67, 101, 135 kg N ha^{-1}), were implemented at dormancy break from late March to mid-April. Plots were 3 by 3 m in size with 1.5 m borders. Nitrogen was broadcast as Agrotain ultra-treated urea (Koch Agronomic Services, LLC, Wichita, KS). The winter cereals were harvested for forage at a cutting height of 10 cm in May of each year at Feekes stage 9 (Zadoks et al., 1974), when the flag-leaf was present but seed heads not yet emerged. Yield was determined by hand-harvesting three, 99 x 20 cm frames at a 10 cm harvest height within each plot. Forage samples were dried at 55˚C and ground to pass a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) and submitted to Brookside Laboratories Inc. (New Bremen, OH) for total C and N determination via combustion analysis using an element analyzer (Vario EL cube, Elementar, Germany). Forage N content was used for calculating apparent N recovery (ANR) for each trial (Table 3.1, Eq. 10).

Statistical Models and Analysis

Yield response data for each trial were categorized into one of four groups: (1) site had no yield response (MERN = 0 kg N ha^{-1}); (2) site was responsive to N addition, but without a yield plateau or a predicted yield plateau beyond the highest N rate of 135 kg N ha^{-1} (MERN > 135 kg N ha^{-1}); (3) site was responsive to N addition and had a yield plateau, but the associated MERN occurred between 0 and 34 kg N ha^{-1}, the lowest N rate (MERN ≤ 34 kg N ha^{-1}); and (4) site was responsive to N addition and had a MERN between 34 and 135 kg N ha^{-1}. For the trials in group 4, quadratic plateau, exponential, and square root plateau models were fitted to the yield data of each trial individually to evaluate the impact of model selection and varying environmental and economic scenarios on site-specific MERNs.

Whether a site belonged to group 1 was determined through linear regression and ANOVA analysis using the aov package in R statistical software (R Core Team, 2015). Trials were classified as group 1 if the ANOVA analysis showed that there were no differences in yield between the different N treatments. A linear plateau model using the nls package in R was used to determine whether a site belonged in groups 2, 3, or 4. Group 2 trials lacked a yield plateau within the range of N rate treatments. Trials were classified as group 3 if the predicted yield plateau occurred at N rates less than 40 kg N ha^{-1} with an associated MERN between 0 and 34 kg N ha^{-1}. For group 4 trials, the predicted yield plateau was between 40 and 134 kg N ha^{-1} with a MERN between 34 and 135 kg N ha^{-1}. Table 3.3 shows a summary of the yield response categories.

Table 3.3. Description of categories for forage winter cereal yield responses to N fertilizer. Trials (n = 63) were separated into four groups categorized by the most economic rate of N (MERN) prediction and presence of a yield plateau.

Group	MERN kg N ha^{-1}	Yield Plateau kg N ha^{-1}	Statistical Methods	Software
1	0	na†	Linear regression, ANOVA	aov R package
2	> 135	> 135	Linear plateau model	nls R package
3	< 34	< 40	Linear plateau, quadratic plateau, exponential, square root plateau models	nls R package
4	34 < MERN < 135	40 < Plateau < 135	Linear plateau, quadratic plateau, exponential, square root plateau models	nls R package

†na, not applicable.

For trials in group 4, the quadratic plateau, square root plateau, and exponential models (Table 3.1, Eq. 7.1-9.2) were evaluated. For each individual location, the maximum yield, or y-coordinate of the plateau, was set based on the value predicted by the linear plateau model, and the intercept was set to be the average value of the yield at the 0 kg N ha^{-1} treatment resulting in an unbiased estimate of the intercept. The quadratic and linear plateau models were not included in the analyses of trials in group 4 because neither of these models are representative of yield response for group 4 trials.

Model Selection Criteria

Models were compared for each trial in group 4 using both statistical and risk assessment criteria to evaluate both goodness of fit and potential economic and/or environmental drawbacks for choosing each model. The coefficient of determination (R^2) was used to determine the goodness of fit of each model (*qpcR* package in R [Speiss, 2014; R Core Team, 2015]), measured by the squared correlation between the observed and predicted yields (not the proportion of variance explained for each model). The model with the highest R^2 value had the best goodness of fit.

To demonstrate the economic risk of choosing the different models, the stability of the MERNs, or resistance to change in different scenarios, predicted by each model was tested by using different price ratios in equations 7.2, 8.2, and 9.2 (Table 3.1). While N fertilizer cost was set at $1.26 per kg N, the MERN was calculated at forage values of $143.30 ("high" price ratio), $198.42 ("medium" price ratio), and $242.51 ("low" price ratio) per Mg of DM. The model with the most stable

MERN under different price ratios was considered the least risky and most preferred for the development of a crop N recommendation system across fields.

Environmental risk was evaluated using the ANR at the calculated MERN as well as 22 kg N ha^{-1} above and below the MERN to measure environmental stability between N rates for each location-model combination (Table 3.1, Eq. 10) (Ketterings et al., 2007). In using a 42 kg N ha^{-1} range of N rates about the MERN, we are assessing the stability of the MERN prediction by each model if a farmer were to under- or over-apply N on a particular field. The 42 kg N ha^{-1} range is subjective yet reasonable for farmers in this region.

Economic Risk

Economic loss from choosing a model that did not fit the data the best was assessed. For each trial, the quadratic plateau, exponential, and square root plateau models, respectively, were set as the "correct" model and resulting economic loss from choosing one of the other models ("incorrect") was calculated (Table 3.1, Eq. 11). For comparisons of all parameters across trials, PROC GLM of SAS (SAS Institute, 1999) was used.

RESULTS

Trial Classification and Model Predictions

Twenty out of 63 trials did not respond to added N and were classified as group 1 trials (MERN = 0 kg N ha^{-1}). This included 15 trials in 2013, three trials in 2014, and one trial each in 2015 and 2016. Yields ranged from 0.5 to 6.9 Mg DM ha^{-1}

with an average of 4.0 Mg DM ha^{-1}. An example of a non-responsive trial can be found in Figure 3.1a, which produced an average yield of 2.5 Mg DM ha^{-1}.

Only one trial in 2013 lacked a yield plateau and was classified as group 2 (Figure 3.1b). For this trial, yield at the zero N rate was 4.5 Mg DM ha^{-1} and increased linearly to 5.5 Mg DM ha^{-1} when 135 kg N ha^{-1} was added.

There were seven trials that had a yield plateau below the 40 kg N ha^{-1} threshold and associated MERN $\leq$ 34 kg N ha^{-1} (group 3), including two trials in 2013, four trials in 2014, and one trial in 2015 (example in Figure 3.1c). Maximum yield values for group 3 trials ranged from 1.6 to 5.4 Mg DM ha^{-1}, averaging 2.8 Mg DM ha^{-1} across the seven trials.

The remaining 35 trials had a yield plateau between 40 and 135 kg N ha^{-1} (group 4) including 24 trials in 2013, seven trials in 2014, and four trials in 2015 (example in Figure 3.1d). The quadratic plateau model predicted MERNs ranging from 47 to 112 kg N ha^{-1} with an average of 77 kg N ha^{-1}, and yields at the MERN ranging from 2.2 to 6.9 Mg DM ha^{-1} with an average of 4.2 Mg DM ha^{-1} (Table 3.4). The exponential model predicted MERNs ranging from 35 to 97 kg N ha^{-1}, averaging 64 kg N ha^{-1}, and yields at the MERN ranging from 2.0 to 6.7 Mg DM ha^{-1}, averaging 4.1 Mg DM ha^{-1}. The MERNs predicted with the square root plateau model ranged from 24 to 92 kg N ha^{-1}, averaging 55 kg N ha^{-1}, while yields at the MERN ranged from 2.0 to 6.7 Mg DM ha^{-1} and averaged 4.0 Mg DM ha^{-1}.

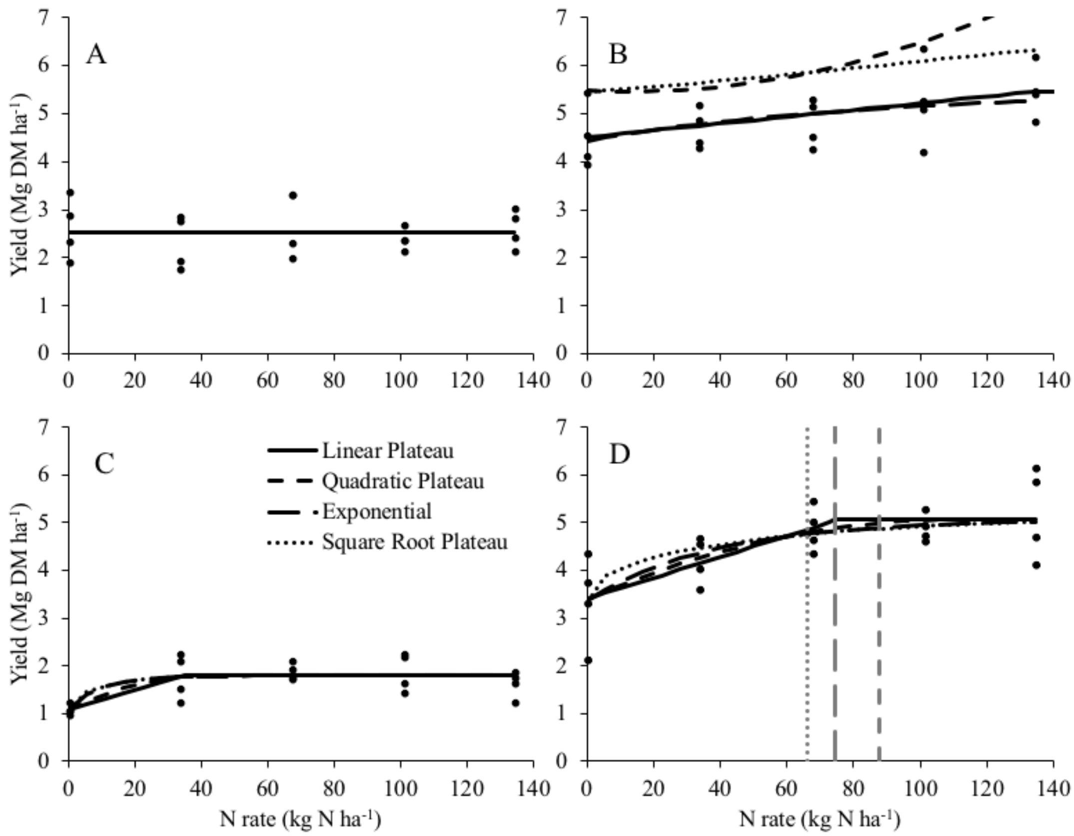

Figure 3.1. Yield response curves of four forage winter cereal N-rate trials representing each of the four yield response groups. Trial A was non-responsive to N fertilizer (group 1) where the line represents the average yield. Trial B had a yield plateau beyond the highest rate of N applied (group 2), trial C had a predicted MERN below the lowest rate of N applied (group 3), and trial D had a plateau between the lowest and highest N rate and a predictable most economic rate of N (MERN) (group 4). For B, C, and D, lines represent the yield response curves of four different models (linear plateau, quadratic plateau, exponential, and square root plateau). For D, vertical grey lines represent the predicted MERNs for the quadratic plateau, exponential, and square root plateau models. Data points are the raw yield data.

Table 3.4. Predicted most economic rates of N (MERN), yield at the MERN, and associated R^2 for 35 triticale (T), cereal rye (R), and winter wheat (W) N-rate trials with MERNs between 40 and 135 kg N ha^{-1}. Three predictive models were assessed for each trial, including the quadratic plateau (QP), exponential (E), and square root plateau (SRP).

	MERN			Yield at MERN			R^2		
	------- kg N ha^{-1}-------			---- Mg DM ha^{-1}------					
Trial	QP	E	SRP	QP	E	SRP	QP	E	SRP
--2013--									
2 T	75.2	64.9	61.0	2.2	2.2	2.0	0.840	0.844†	0.843
8 T	48.1	44.5	44.5	6.0	6.0	6.0	0.534†	0.533	0.533
9 R	80.5	62.2	46.6	3.8	3.6	3.6	0.699†	0.692	0.678
11 T	68.3	62.1	55.8	4.9	4.7	4.7	0.733†	0.718	0.708
12 T	72.9	59.4	50.7	2.5	2.2	2.2	0.807†	0.799	0.792
13 T	47.0	35.4	23.5	3.8	3.8	3.8	0.450†	0.436	0.430
14 T	71.5	54.7	40.1	4.0	4.0	3.8	0.367†	0.361	0.356
16 T	89.8	74.1	63.4	6.3	6.0	6.0	0.551†	0.548	0.540
19 T	84.4	63.3	44.6	6.5	6.3	6.3	0.599†	0.585	0.561
20 T	81.4	86.8	92.2	4.9	4.7	4.7	0.808†	0.802	0.794
22 T	87.9	74.5	66.4	4.9	4.9	4.7	0.729†	0.727	0.718
25 T	74.9	61.1	55.1	2.9	2.7	2.7	0.716	0.718†	0.716
26 T	102.3	79.0	60.2	4.9	4.9	4.7	0.580	0.584†	0.582
28 T	93.4	72.6	54.1	3.1	2.9	2.7	0.570†	0.558	0.541
29 T	88.5	70.4	52.7	5.8	5.8	5.6	0.638†	0.616	0.589
33 T	61.3	51.9	47.2	2.9	2.7	2.7	0.560†	0.554	0.552
34 W	83.4	76.1	73.5	2.9	2.9	2.9	0.918	0.919†	0.914
35 W	104.5	87.7	74.5	3.6	3.4	3.1	0.844†	0.830	0.805
36 T	89.3	75.7	65.8	3.6	3.4	3.4	0.858†	0.849	0.834
38 R	83.2	66.7	56.0	4.0	4.0	3.8	0.574	0.576†	0.575
39 R	63.1	59.3	58.8	5.2	5.2	5.2	0.696†	0.689	0.686
40 R	83.3	63.7	41.9	2.2	2.0	2.0	0.519	0.528	0.532†
41 R	98.7	75.9	59.2	5.4	5.4	5.2	0.731	0.751	0.757†
42 T	76.0	59.4	50.4	6.9	6.7	6.7	0.570†	0.566	0.562
--2014--									
43 R	112.3	96.7	86.1	5.2	4.9	4.7	0.842†	0.826	0.797
45 R	48.8	48.8	52.1	3.6	3.6	3.6	0.897	0.897	0.897
47 T	70.3	68.9	67.8	4.3	4.0	4.0	na‡	na‡	na‡
51 R	67.4	50.8	37.3	4.0	4.0	3.8	0.526	0.530	0.530
54 T	47.6	41.8	30.0	5.2	5.4	5.2	na‡	na‡	na‡
55 R	94.9	84.2	77.1	4.5	4.3	4.3	0.913†	0.901	0.88
56 R	73.8	61.2	54.6	3.8	3.8	3.6	0.922	0.922	0.919
--2015--									
57 R	56.7	49.1	45.4	3.4	3.1	3.1	0.840†	0.839	0.838
58 R	57.5	43.4	28.8	2.2	2.2	2.2	0.436	0.443	0.447†
59 T	59.6	44.7	32.6	3.1	3.1	3.1	0.483	0.485†	0.483
61 T	101.3	83.6	72.4	3.1	2.9	2.9	0.895†	0.887	0.872

†Denotes best fit based on statistical criteria (largest R^2 value).
‡na, not applicable.

For 94% of trials in group 4, the quadratic plateau model predicted the highest MERN, followed by the exponential and square root models (Table 3.4). The square root plateau model predicted the highest MERN for only two trials, while the exponential model was consistently intermediate. Across all group 4 trials, the quadratic plateau model predicted the highest MERN ($P < 0.0001$), followed by the exponential and square root models (Figure 3.2a). For yield at the MERN predictions, there were no differences among the models ($P = 0.806$) (Figure 3.2b), suggesting that this variable is not as sensitive to model selection.

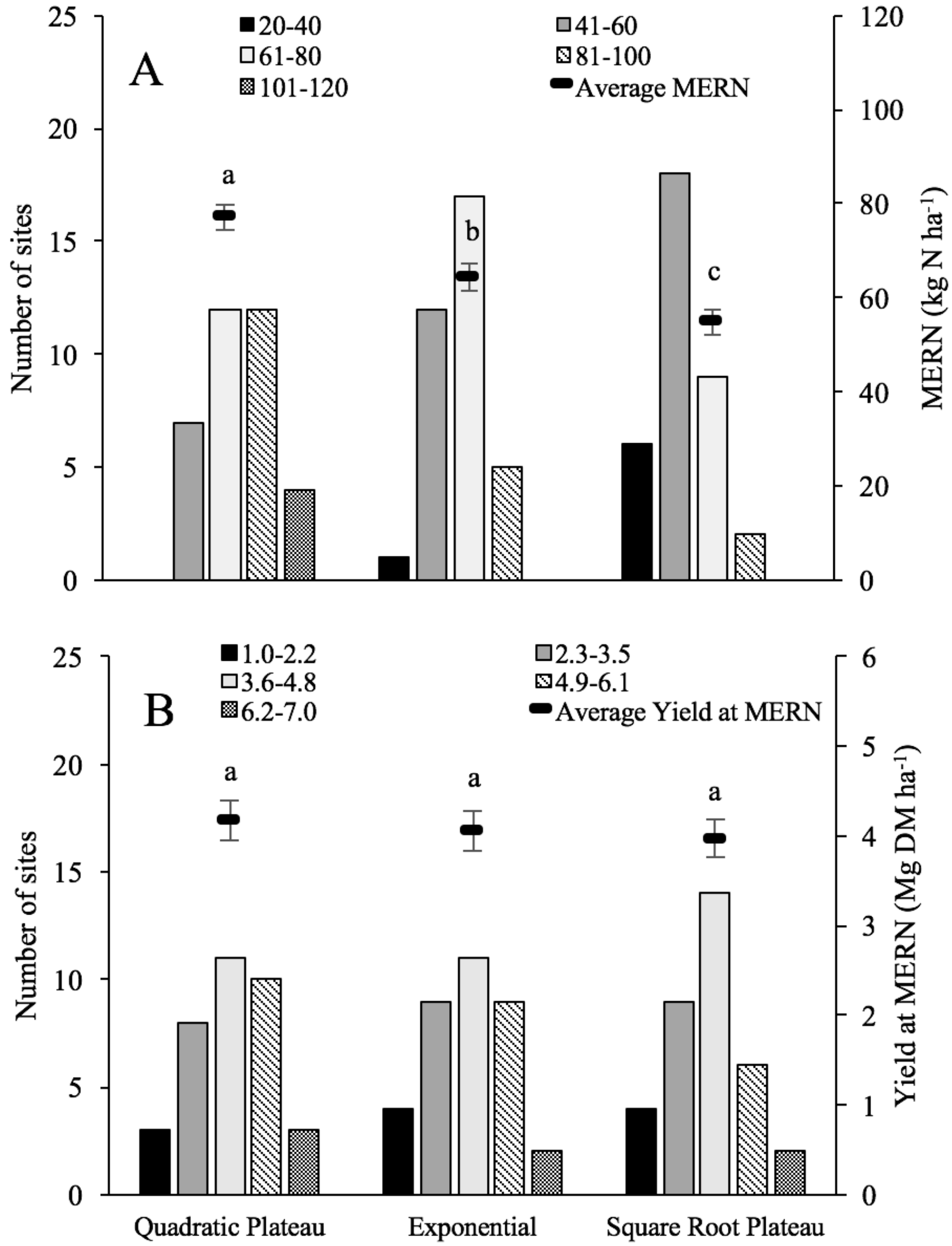

Figure 3.2. Number of forage winter cereal N-rate trials with most economic rates of N (MERN) (kg N ha^{-1}) (A) and yields at the MERN (Mg DM ha^{-1}) (B) within a specified range according to three statistical models (quadratic plateau, exponential, and square root plateau), as well as the average MERN (A) and yields at the MERN (B) predicted by each model across all responsive trials (group 4). Error bars represent 1 SE, and different letters represent significant differences in MERN (A) or yield at the MERN (B) ($P \leq 0.05$).

Model Selection Criteria

For 21 of the group 4 trials (60%), the quadratic plateau model had the highest R^2 value as compared to the other two models. The exponential model had six trials with the highest R^2 value, followed by the square root plateau model with only three trials with the highest R^2 (Table 3.4). There were no differences in R^2 values among the models when all trials were combined, likely due to the large variability in R^2 values among trials as well as relatively small differences in R^2 among models within trials. The R^2 averaged 0.69, 0.68, and 0.68 for the quadratic plateau, exponential, and square root plateau models, respectively. Although there were no differences in R^2 among models when all trials were combined, assessing trials on an individual basis using this criterion can aid with model selection.

All three models showed differences in ANR between the MERN, MERN + 22 kg N ha^{-1}, and MERN – 22 kg N ha^{-1} at a medium price ratio (P = 0.0156, < 0.0001, and 0.0001 for the quadratic plateau, exponential, and square root plateau models, respectively) (Figure 3.3). The quadratic and exponential models had higher ANRs when 22 kg N ha^{-1} less than the MERN was applied, while application at the MERN and MERN + 22 kg N ha^{-1} had similar ANRs. For the square root plateau model, applying 22 kg N ha^{-1} less than the MERN had significantly higher predicted ANRs than applying MERN + 22 kg N ha^{-1}; however, neither were different from the ANR at the MERN.

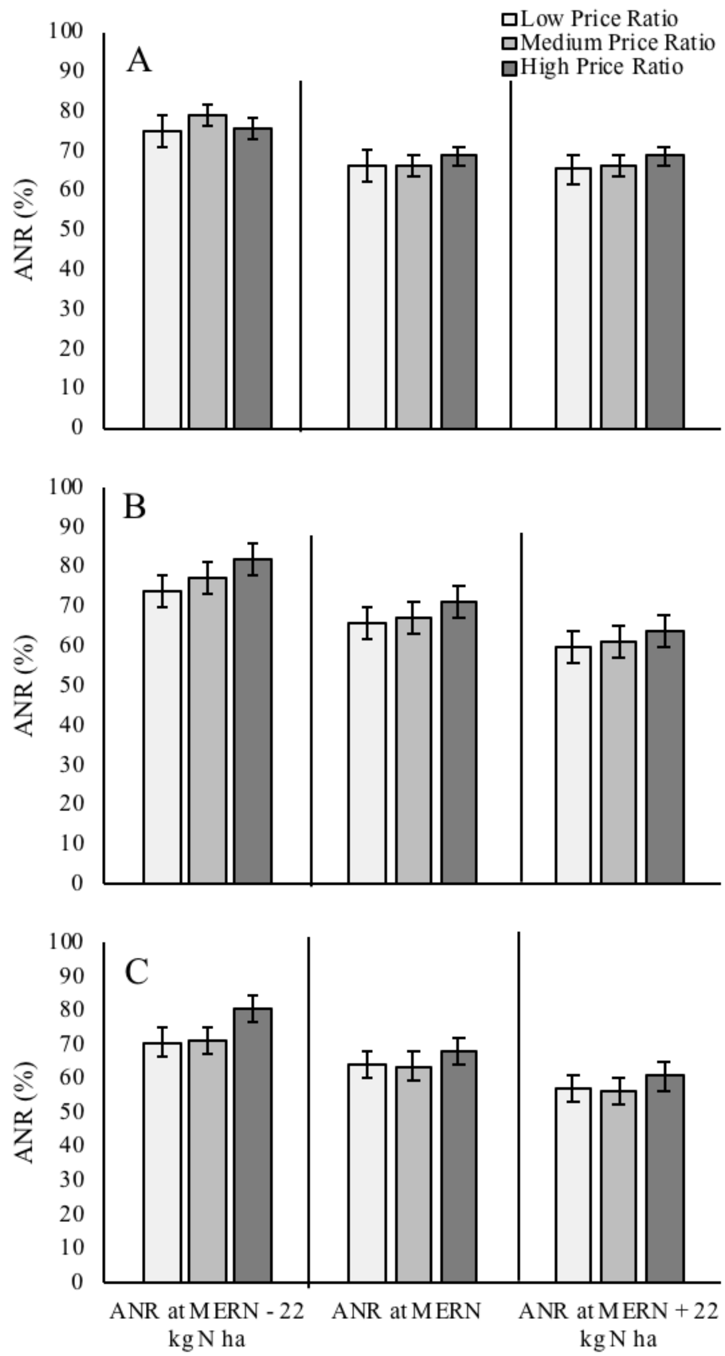

Figure 3.3. Apparent N recovery (ANR) across 35 forage winter cereal trials based on price ratio and N application for the quadratic plateau model (A), exponential model (B), and square root plateau model (C). Price ratios assumed a fixed N cost of \$1.26 kg^{-1} N with forage values of \$242.51 Mg^{-1} DM (low), \$198.42 Mg^{-1} DM (medium), and \$143.30 Mg^{-1} (high).

Models were similar in the difference in ANR values between MERN + 22 kg N ha^{-1} and MERN - 22 kg N ha^{-1} (P = 0.7174), indicating that models were equally stable in ANR if fertilizer is over- or under-applied. There were no interactions among model, price ratio, and N application (MERN, MERN + 22 kg N ha^{-1}, and MERN – 22 kg N ha^{-1}) on ANR.

The three models resulted in different MERNs and associated yields at the MERN as well as ANR predictions under varying price ratios and MERN rates (Table 3.5). Small differences in predictions among price ratios indicated greater economic stability. The quadratic plateau and exponential models had lower differences in both MERN (P = 0.0021) and yield at the MERN (P = 0.0055) predictions between the high and low-price ratios as compared to the square root plateau model. For MERN - 22 kg N ha^{-1}, the quadratic plateau model predicted that yield was least impacted by price ratio, followed by the exponential and square root plateau models ($P < 0.0001$) (Figure 3.4a and Table 3.5). However, for MERN + 22 kg N ha^{-1}, all models predicted similar differences in yield between the high and low-price ratios (P = 0.10). The quadratic plateau model had the lowest difference between high and low-price ratios for both ANR at the MERN ($P < 0.0001$) and ANR at MERN -22 kg N ha^{-1} (P = 0.0014), followed by the square root plateau and exponential models (Figure 3.4b). For ANR at the MERN + 22 kg N ha^{-1}, all three models had similar differences in ANR between the high and low-price ratios (P = 0.60).

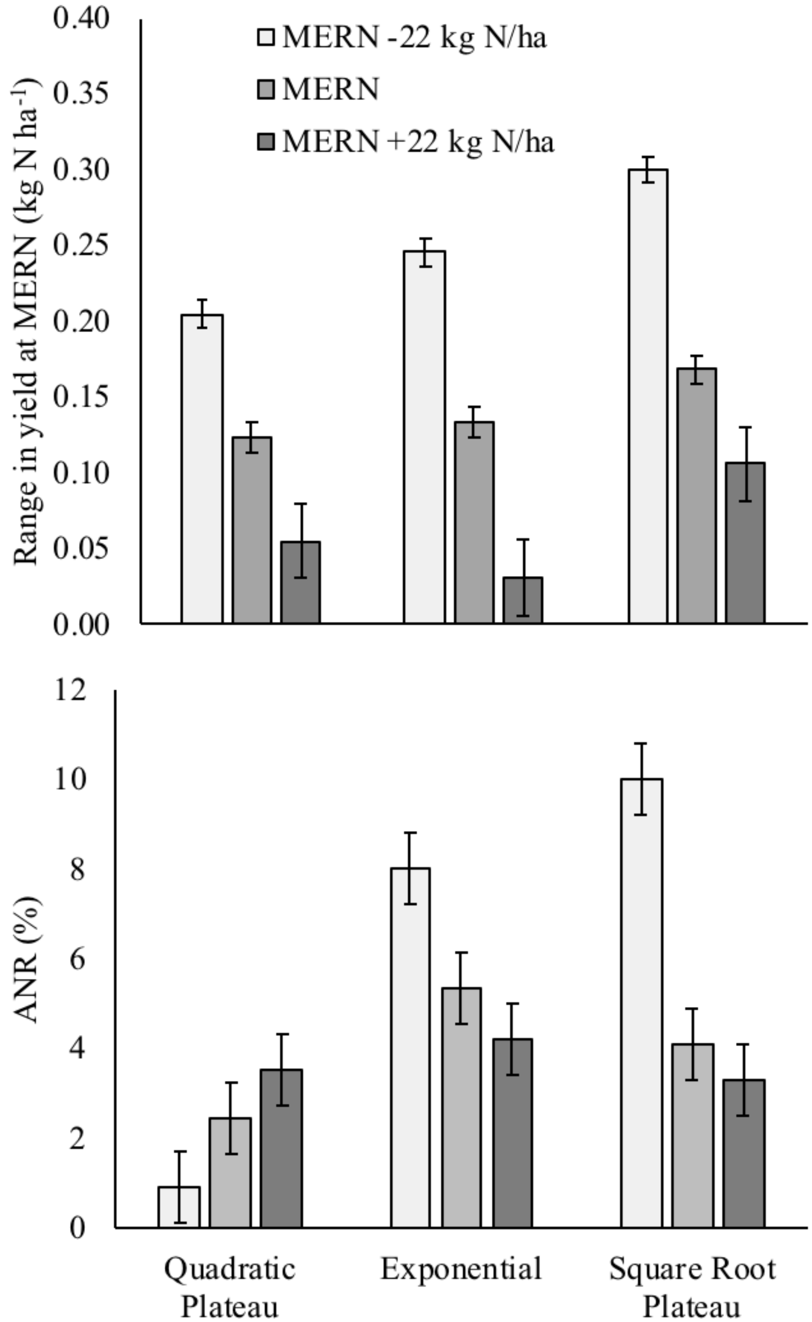

Figure 3.4. Range in yield at the most economic rate of N (MERN) (A) and apparent N recovery (ANR) (B) of 35 winter cereal N-rate trials between a high and low-price ratio at the MERN, MERN – 22 kg N ha^{-1}, and MERN + 22 kg N ha^{-1} as predicted with a quadratic plateau, exponential, or square root plateau model. The greater the range, the less stable the model is across varying price ratios and N applications.

Table 3.5. Economic and environmental stability of the most economic rate of N (MERN) predictions for forage winter cereals estimated with the quadratic plateau (QP), exponential (E), and square root plateau (SRP) models across three fertilizer cost to forage value ratios. Values are the difference between the high (\$143.30 Mg^{-1} DM and \$1.26 kg^{-1} N) and low (\$242.51 Mg^{-1} DM and \$1.26 kg^{-1} N) price ratios.

	Difference in MERN			Difference in ANR at MERN			Difference in ANR at MERN – 22 kg N ha^{-1}			Difference in ANR at MERN + 22 kg N ha^{-1}		
	--- kg N ha^{-1}--			------- % -------			------- % -------			-------- % ------		
Trial	QP	E	SRP	QP	E	SRP	QP	E	SRP	QP	E	SRP
						2013						
2	10†	16	24	3.2†	7.4	3.7	1.8†	10.3	6.4	3.2	5.3	2.5†
8	4†	9	12	2.6†	7.4	2.7	1.3†	14.6	6.9	2.6	4.1	1.5†
9	22	22	25	2.4†	5.0	4.9	0.1†	5.7	8.3	2.4†	4.0	3.3
11	8†	16	24	2.7†	6.0	2.9	-0.5†	8.1	5.4	2.7	4.4	1.9†
12	13†	17	23	2.2†	4.8	3.1	0.7†	6.5	5.6	2.2	3.5	2.1†
13	33	17	14†	2.6†	5.1	15.5	3.0†	-4.5	96.8	2.6†	3.8	7.6
14	21	20†	22	1.5†	3.4	3.6	-0.9†	3.9	6.8	1.5†	2.7	2.3
16	16†	21	29	1.5†	3.5	2.3	0.1†	4.1	3.6	1.5†	2.8	1.6
19	31	25†	26	2.0†	3.8	5.2	-2.0†	3.4	8.6	2.0†	3.3	3.6
20	5†	17	24	1.7	4.9	1.4†	0.4†	6.6	2.2	1.7	3.7	1.0†
22	13†	20	29	2.6†	5.6	3.2	1.0†	7.0	5.1	2.6	4.3	2.3†
25	12†	16	24	2.6†	6.0	3.5	2.5†	8.6	6.1	2.8	4.2	2.3†
26	31	28†	33	1.9†	4.0	4.0	1.8†	4.9	6.2	1.9†	3.3	2.9
28	26	26	30	0.8†	2.8	3.3	-2.5	2.4†	5.3	0.8†	2.6	2.3
29	21†	25	29	1.1†	2.5	2.3	-1.6†	2.3	3.7	1.1†	2.2	1.6
33	8†	13	18	4.2†	9.3	4.8	2.7†	14.9	9.7	4.2	5.9	3.0†
34	9†	18	28	2.5†	5.9	2.6	1.1†	7.8	4.2	2.5	4.4	1.8†
35	18†	26	35	2.7†	5.5	3.5	1.0†	6.4	5.0	2.7	4.5	2.6†
36	14†	21	30	3.0†	6.2	3.6	1.7†	8.0	5.7	3.0	4.8	2.6†
38	17†	20	27	3.9†	7.5	5.1	4.1†	10.3	8.4	3.9	5.5	3.5†
39	5†	13	18	3.6†	9.7	3.6	2.2†	15.6	7.1	3.6	6.3	2.3†
40	45	29	26†	2.2†	3.8	7.4	16.0	5.2†	13.9	2.2†	3.1	4.7
41	29	25†	32	2.1†	4.4	4.3	2.8†	5.6	6.8	2.1†	3.6	3.1
42	15†	17	23	2.8†	5.6	4.0	2.6†	7.9	7.0	2.8	4.0	2.7†
						2014						
43	17†	27	38	1.9†	4.2	2.4	0.5†	4.8	3.3	1.9	3.5	1.8†
45	3†	9	13	3.3	10.5	3.0†	2.0†	20.3	7.7	3.3	5.9	1.7†
47	6†	15	22	0.0	0.0	0.0	1.1†	9.9	4.4	2.6	4.7	1.7†
51	22	18†	21	3.4†	6.0	6.4	10.3	8.7†	12.8	3.4†	4.3	4.0
54	54	14†	18	0.0	0.0	0.0	-32.0	17.6†	na‡	35.4	5.5†	21.8
55	12†	22	32	2.2†	4.9	2.5	0.4†	5.9	3.8	2.2	4.0	1.8†
56	12†	17	24	4.2†	8.9	5.1	3.7†	12.8	9.0	4.2	6.3	3.4†
						2015						
57	7†	12	18	3.0†	6.8	3.4	1.3†	11.1	7.4	3.0	4.4	2.1†
58	31	19	18†	3.2†	5.0	9.5	-16.1	8.5†	26.8	3.2†	3.6	5.3
59	20	17†	18	3.6†	6.6	7.3	20.9	9.1†	16.5	3.6†	4.6	4.4
61	18†	24	33	2.1†	4.5	2.9	0.9†	5.5	4.3	2.1†	3.7	2.2

†Denotes smallest difference between the high and low-price ratios for each trial.
‡na, not applicable.

Economic Risk of Model Selection

The economic loss was highest when the model that best fit the data was the quadratic plateau model but the exponential or square root plateau model was used to determine the MERNs (- \$1.34 ha^{-1} average loss). The predicted economic loss for choosing a different model if the exponential model was the best fit was - \$0.48 ha^{-1}, versus - \$0.69 ha^{-1} if the square root plateau model was the best fit (Figure 3.5).

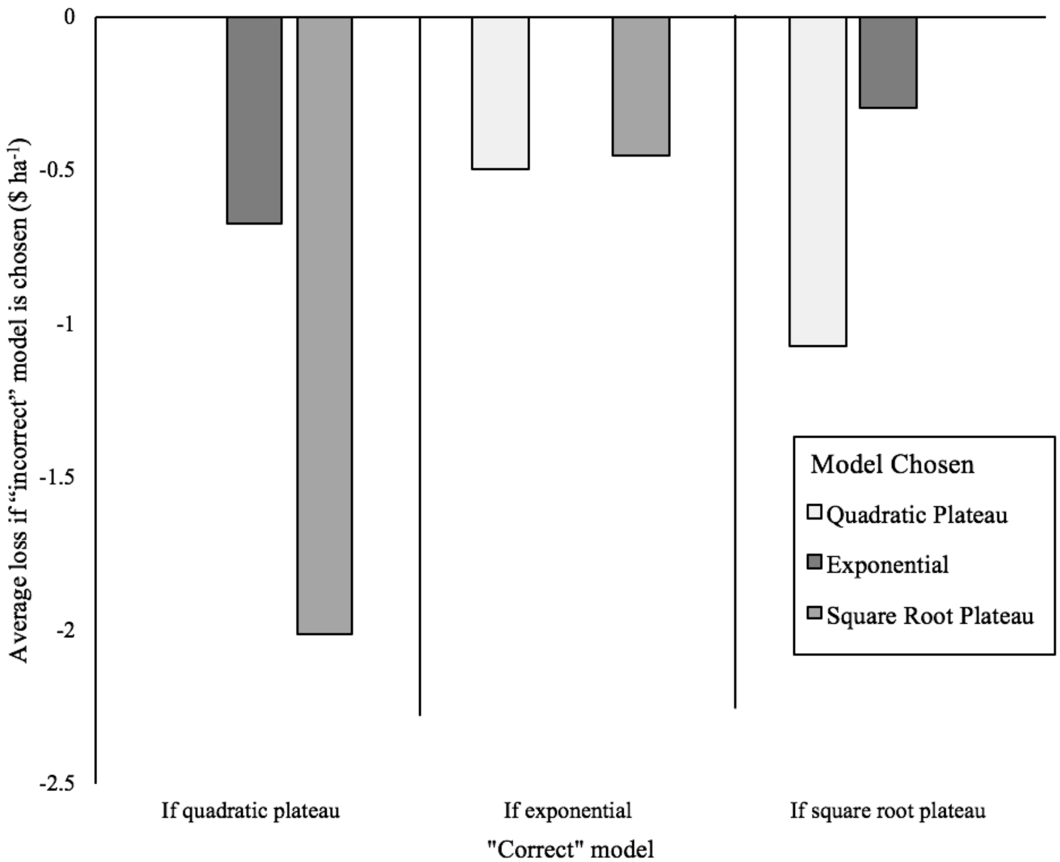

Figure 3.5. Economic loss if an "incorrect" model is chosen averaged over 35 winter cereal trials responsive to N fertilization. For each combination of models, the yield was calculated by the "correct" model based on the most economic rate of N (MERN) determined by the "incorrect" model.

DISCUSSION

Studies have been conducted in numerous regions and cropping systems to determine N needs for winter cereals such as wheat, barley, and cereal rye, but most of the research is focused on grain production. There are important management differences between growing winter cereals for grain versus forage, including timing and amount of N fertilizer. Studies investigating N needs for wheat or barley grain often split N applications between the fall (at or just after planting) and one or more growth stages in the spring (Ellen and Spiertz, 1975, 1980; Alcoz et al., 1993; Ayoub et al., 1994; Delogu et al., 1998; Arregui and Quemada, 2008; Cui et al., 2010). In general for grain production, N is applied at tiller initiation with recommendations for a split application at a later growth stage, such as stem elongation, boot, or antithesis, to reduce risk of lodging and increase NUE (Ayoub et al., 1994; Cui et al., 2010; Dilz, 1971; Ellen and Spiertz, 1980; Sowers et al., 1994). In contrast, N management for winter cereals grown for forage with harvest at the flag-leaf or boot stage is restricted to a single N application at dormancy break (Boman et al., 1995). In the current study, the forage winter cereals represented a wide range of yield responses to N. This is likely due to the variety of field conditions across trials, including soil physical, biological and chemical properties, weather, and crop and soil management practices. For example, trials with recent manure or legume histories are more likely to have significant levels of plant-available N when the winter cereals need it and thus be less responsive to additional N than others (as was the case in this study). Similarly, trials with poorly drained soils may support lower yields and thus impact crop responsiveness to N. The field characteristics of the trials in our study will be further investigated for such differences in soil properties and management in a follow-up article, where trial results are combined for the development of a statewide N recommendation system.

Cerrato and Blackmer (1990) concluded that for corn receiving N shortly before planting, a model's R^2 value is not a reliable selection criterion, despite its common use as justification for model selection, given different models can have the same or similar R^2 while predicting very different MERNs. Results of our studies with winter cereals grown for forage showed variations in R^2 among models for the same trial, in addition to differences in MERNs, with typically the highest R^2 for the quadratic plateau model. These results suggest that for winter cereals grown for forage with a three to four week growth window, the R^2 of the model is an appropriate selection criterion.

Studies comparing statistical models for determining optimum N needs for winter cereal forages are limited. One study in Oklahoma investigated the best statistical model for determining the MERN of rye-ryegrass forage, but their dataset was comprised of many years of data from a single location and so a stochastic model was chosen (Tumusiime et al., 2011). In the current study, one year of data was collected from each location, reflecting crop rotations and seasonal adjustments in the region, and so a stochastic model is not appropriate for determining MERNs.

Studies with corn grown for grain in Iowa (Cerrato and Blackmer, 1990) and Quebec (Isfan et al., 1995), with N rates applied at or before planting, showed that the quadratic plateau model most often predicted the lowest MERN as compared to exponential and square root models (Cerrato and Blackmer, 1990) and quadratic and linear plateau models (Isfan et al., 1995). In contrast, in our work with winter cereals grown for forage in New York, the quadratic plateau model most often predicted the highest MERNs (in addition to having the highest R^2). The inconsistency in results among these studies emphasizes the need for crop- and region-specific model determination for predicting MERNs.

Environmental and economic indicators suggested the quadratic plateau model to be the best fitting model across locations as well, as it minimized both environmental impacts and economic losses at varying ratios of forage value and fertilizer cost. To our knowledge, no comparison studies are available in the scientific literature with winter cereals grown as forage in corn silage rotations, but our findings are consistent with a similar assessment of N needs for potato in New Brunswick, Canada, where the quadratic model posed the least amount of risk compared to other models (Bélanger et al., 2000). In their study, the square root or exponential models resulted in predictions of economic loss in situations where the quadratic model was the most appropriate fit for the data. When either the square root or exponential model was the better fit for the data, but the quadratic model was used, in most cases (75%) a financial gain was still predicted (Bélanger et al., 2000).

Forage winter cereals grown in double cropping rotations in the northeastern USA present a unique forage system, as the growing period for these crops between dormancy break and flag-leaf stage in the spring is typically limited to three to four weeks. Literature on fertility management of short-season forage winter cereals is limited nationwide and to our knowledge non-existent in the northeastern USA. Our findings show that while data from a few individual trials fit exponential or square root models best, the quadratic plateau model provided the best fit for the majority of trials that showed a crop response to N application at dormancy break.

CONCLUSIONS

Yield response data showed that N recommendation systems for winter cereals grown as forages in New York should recognize four groups of responses for individual trials: (1) no yield response to N; (2) yield plateau exceeded the highest N rate; (3) the MERN was below the lowest N rate; and (4) all other N responsive trials. For trials responsive to N, the quadratic plateau model was the preferred model based on statistical criteria. In addition, the quadratic plateau model had consistently lower ranges (uncertainties) in ANR, MERN, and yield at the MERN between high and low-price ratios as compared to the other two models. Although the quadratic plateau model may not be ideal for determining the MERN for every crop species and/or region, we conclude (1) the quadratic plateau model is most appropriate for predicting the MERNs of winter cereals grown as forage double crops in New York, and (2) the categorization-based approach evaluated in this study (dividing trials into four groups based on yield response characteristics) can be applied to alternative scenarios that include different crop yield responses, predictor models, statistical selection criteria, and environmental and/or economic standards depending on the cropping system. Research is ongoing to develop a yield prediction and N recommendation system for winter forages in the northeastern USA for trials in groups 1, 3, and 4 based on individual field characteristics such as soil type, soil fertility, and management practices, and the recognition that the time between dormancy break and forage harvest is typically just three to four weeks.

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CHAPTER 4: NITROGEN MANAGEMENT FOR FORAGE WINTER CEREALS IN THE NORTHEASTERN USA[1]

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ABSTRACT

Forage double cropping can be a beneficial practice for dairy farmers in the northeastern United States, providing an additional, harvestable crop plus many environmental benefits. Triticale (x *Triticosecale* Wittm.), winter wheat (*Triticum aestivum* L.), and cereal rye (*Secale cereale* L.) are forage double crop options in New York that require nitrogen (N) management. From 2013 to 2016, 62 N-rate trials were conducted across New York with five N rates (0, 34, 67, 101, and 135 kg N ha^{-1}) applied in four replications at spring dormancy break. Forage was harvested at flag-leaf stage in May (Feekes stage 9). Soil samples were taken prior to N-application at dormancy break. Management practices and field characteristics were evaluated as

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predictors (using classification tree analyses) for yield and the most economic rate of N (MERN) at dormancy break, determined using a quadratic plateau model. About 1/3rd of the sites did not respond in yield to spring N application, averaging 4.3 Mg DM ha^{-1} yield. Of the remaining sites, about 80% had MERNs ranging from 47 to 112 kg N ha^{-1}, averaging 77 kg N ha^{-1}, with yields at the MERN from 2.2 to 6.9 Mg DM ha^{-1}, averaging 4.2 Mg DM ha^{-1}. Yield could not accurately be predicted statistically. However, low-yielding sites lacked fall manure application and well-drained soils. We conclude that forage winter cereal fields with well-drained soils, recent manure applications, and timely planting may not need additional N at dormancy break, while others require approximately 19 kg N ha^{-1} per Mg DM ha^{-1}.

INTRODUCTION

The most common forage rotation in the northeastern United States includes corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.)/grass hay every three to four years. Rather than leaving the soil bare over the winter months during the corn silage years, cover cropping with cool-season crops is becoming more popular as interest in improving soil health continues to grow (Long et al., 2013). Cover cropping has been shown to lower the risk of soil erosion, enhance rotation diversity, increase soil organic matter (SOM), suppress weeds, and reduce nutrient loss to the environment (Kaspar et al., 2001; Dabney et al., 2001; Feyereisen et al., 2006; Mirsky et al., 2011; Long et al., 2013; Moore et al., 2014; Ketterings et al., 2015b). Cover cropping with cool season annual cereal grains has also been shown to positively influence the main crop yields through soil and water conservation (Clark et al., 1997; Truman et al., 2003), N supply (Reeves, 1994; Blanco-Canqui et al., 2015), and weed suppression (Teasdale and Mohler, 2000; Hartwig and Ammon, 2002).

Driven initially by a severe drought that impacted forage supplies (Long et al., 2013), some farmers in New York started to harvest fields with winter-hardy cover crops such as cereal rye, wheat, and triticale for forage in the spring, prior to planting of the main season crop (Ketterings et al., 2015a), defined here as double cropping. The benefits of double cropping not only include the full-season yield and spreading of crop production risk (two harvests instead of one), but also most of the benefits normally attributed to cover crops.

When winter cereals are grown as double crops in forage rotations, N management at dormancy break in the spring is essential for optimal forage winter cereal performance. A survey conducted among New York corn growers suggested that 79% of those who grew winter cereals for forage applied fertilizer N at dormancy break to achieve higher yields (Ketterings et al., 2015a). A study by Lyons et al. (2018a) showed MERNs ranging from 55 to 128 kg N ha^{-1} for N application at dormancy break for triticale. In contrast, Gibson et al. (2007) investigated the response of triticale to N applied in mid-March in Iowa and found that N uptake by the triticale following corn and soybeans increased with additional N but that the optimal N application was small (33 kg N ha^{-1}) for both triticale grain and forage in the study.

Because of the long winters in the Northeast, dormancy break in the spring occurs between late March and early April. A late dormancy break may only allow winter cereals 3- to 4-wk to reach flag-leaf stage prior to harvest in May. This short window makes the management of this forage rotation in the Northeast unique as compared to other regions. Our objectives were to evaluate field and management characteristics as predictors (using classification tree analyses) for yield and MERN for winter cereals grown for forage in New York.

MATERIALS AND METHODS

Locations and Experimental Design

From 2013 to 2016, 62 winter cereal N rate trials were conducted across New York. All trials were conducted on-farm to reflect realistic farmer scenarios. The trials covered five regions of the state, including the Upper Susquehanna Watershed (southern New York), central, western, eastern, and northern New York, and different 40 soil series. Trials consisted of three winter cereal species, including triticale (n = 38), cereal rye (n = 21), and winter wheat (n = 3). Each spring at dormancy break, fertilizer N in the form of Agrotain-treated urea (Agrotain Ultra, Koch Agronomic Services, LLC, Wichita, KS) was hand-applied at five rates (0, 34, 67, 101, and 135 kg N ha^{-1}) to 3 x 3 m plots with 1.5 m borders in a representative area of the field. Trials were organized in a randomized complete block design with four replications. Prior to fertilization, eight soil cores were taken per plot (0- to 20-cm depth), dried, composited, and submitted for baseline soil fertility analysis (Tables 4.1 and 4.2). In 2015 and 2016 (7 trials), soil sampling was repeated at harvest of the winter cereal as well. This study did not include a species comparison, as each individual trial included a single winter cereal species.

Table 4.1. Baseline soil pH, nitrogen, and organic matter for 62 forage winter cereal N rate trials in New York conducted from 2013 to 2016. Values are averages of 20 soil composites (each containing eight, 0- to 20-cm cores) within each field.

Group	Tria	County	Soil series	pH	NH_4^+‡	NO_3^-, NO_2^-	Active	ISNT¶	ISNT	LOI#	SOM#
					---------------------------- mg kg^{-1}			--------------		---------- g kg^{-1}	---------
1	5	Oneida	Lima	6.5	13.3	2.3	503	210	276	47	30
	6	Rensselaer	Rhinebeck	6.0	12.4	2.0	426	145	246	35	20
	7	St.	Hogansbur	6.2	31.2	3.7	721	314	306	63	38
	10	Clinton	Hailesboro	6.9	23.3	9.1	1178	394	332	92	58
	15	Wyoming	Erie	6.5	29.9	5.9	845	373	324	78	46
	17	Yates	Lansing	5.8	5.7	2.0	484	148	248	36	21
	18	Genesee	Cazenovia	7.3	15.6	6.0	789	257	287	53	33
	21	Genesee	Lima	7.2	6.9	8.2	795	225	276	48	30
	23	Wyoming	Conesus	7.1	13.4	2.2	806	263	295	58	36
	24	Livingston	Howard	6.3	13.5	1.0	526	188	266	43	25
	27	Wyoming	Allard	6.1	34.7	3.3	619	265	305	63	36
	30	Steuben	Howard	6.0	24.3	1.1	567	242	307	65	35
	31	Steuben	Howard	6.5	17.0	1.2	556	163	271	45	25
	37	Madison	Mardin	5.9	23.1	2.8	606	322	318	73	43
	48	Jefferson	Collamer	6.6	24.6	4.4	864	319	310	66	39
	49	St.	Swanton	6.9	27.4	4.4	882	281	293	56	32
	52	Clinton	Bombay	6.3	18.7	5.2	803	285	293	56	34
	60	Cortland	Tioga	6.9	75.3	7.6	1211	480	336	102	64
	63	Wayne	Hilton	6.7	12.3	2.2	558	199	262	41	24
			Average	6.6	22.2	3.9	723	267	292	59	35

Table 4.1 (Continued)

Group	Tria	County	Soil series	pH	NH_4^+ ‡	NO_3^-, NO_2^-	Active	ISNT¶	ISNT	LOI#	SOM#
					---------------------------- mg kg^{-1}			--------------		---------- g kg^{-1}	---------
2	4	Oneida	Lima	6.4	20.0	2.6	619	272	301	62	38
3	1	Cortland	Howard	6.5	75.5	16.9	1181	488	335	97	60
	3	Delaware	Tunkhanno	6.1	24.3	4.3	851	367	328	84	53
	44	Chenango	Unadilla	6.0	32.4	9.0	548	263	301	60	37
	46	Madison	Palmyra	7.1	10.1	6.5	845	401	330	86	51
	50	St. Lawrence	Grenville	7.1	30.9	8.9	944	287	294	57	33
	53	Wyoming	Appleton	6.8	15.5	3.0	661	219	283	51	31
	62	Cortland	Howard	6.9	33.0	6.5	1000	374	332	88	53
			Average	6.6	31.7	7.9	861	343	315	75	45
4	2	Cortland	Lordstown	6.4	40.8	5.0	808	345	323	77	49
	8	St. Lawrence	Swanton	6.5	27.6	4.9	896	381	308	65	41
	9	Clinton	Shaker	6.3	23.3	3.5	486	205	246	35	21
	11	Jefferson	Kingsbury	6.6	27.3	6.3	1108	429	331	87	55
	12	Jefferson	Hinkley	6.8	25.2	2.4	919	289	297	58	37
	13	Lewis	Nellis	6.6	22.6	8.0	1127	532	335	96	63
	14	Genesee	Palmyra	6.8	15.3	2.8	557	199	270	45	25
	16	Livingston	Valois	7.0	22.3	5.2	723	237	299	59	35
	19	Ontario	Honeoye	6.8	14.3	2.1	493	197	264	42	26
	20	Orleans	Madrid	6.7	6.1	3.4	455	118	239	33	20

Table 4.1 (Continued)

Group	Tria	County	Soil series	pH	NH_4^+‡	NO_3^-, NO_2^-	Active	ISNT¶	ISNT	LOI#	SOM#
					---------------------------- mg kg^{-1}			--------------		---------- g kg^{-1}	---------
4	22	Wyoming	Conesus	6.6	15.9	3.5	836	298	306	64	39
	25	Livingston	Copake	6.6	14.8	3.6	399	149	246	35	20
	26	Orleans	Hilton	7.1	7.3	6.8	681	192	276	48	28
	28	Ontario	Ontario	6.3	17.2	4.2	661	239	270	46	27
	29	Steuben	Alton	6.7	17.9	8.1	973	336	321	75	45
	33	Tompkins	Bath	6.7	67.2	4.6	879	394	328	82	47
	34	Cortland	Tioga	5.8	21.2	2.6	603	268	303	62	32
	35	Cortland	Valois	6.9	38.1	4.6	823	399	327	81	49
	36	Cortland	Chagrin	6.6	15.0	4.5	510	218	294	56	32
	38	Madison	Howard	6.6	25.5	3.4	705	253	296	58	33
	39	Madison	Raynham	6.4	16.5	3.8	590	222	288	54	29
	40	Madison	Palmyra	6.9	15.5	6.1	1007	351	329	83	50
	41	Chemung	Unadilla	5.7	8.5	1.6	373	149	273	46	27
	42	Tioga	Middlebury	6.5	15.0	4.2	721	242	305	63	40
	43	Chenango	Chenango	5.8	77.4	2.0	867	444	329	85	53
	45	Chenango	Howard	5.8	57.4	5.1	758	325	307	65	53
	47	Oneida	Appleton	7.4	14.9	3.7	899	319	313	68	41
	51	Clinton	Malone	6.5	18.8	5.2	580	199	257	39	23
	54	Wyoming	Appleton	6.5	10.4	1.2	535	162	256	39	24

Table 4.1 (Continued)

Group	Tria	County	Soil series	pH	NH_4^{+}‡	NO_3^-, NO_2^-	Active	ISNT¶	ISNT	LOI#	SOM#
					-------------------------- mg kg^{-1}			--------------		---------- g kg^{-1}	------
4	55	Delaware	Unadilla	6.3	19.8	1.0	477	164	249	37	22
	56	Delaware	Tunkhannock	6.3	55.8	5.7	1031	423	335	94	59
	57	Montgomery	Nunda	6.9	28.4	2.4	873	293	306	64	37
	58	Montgomery	Burdett	7.0	21.9	4.7	1024	338	320	74	43
	59	Cortland	Howard	7.2	54.1	8.6	1031	378	325	80	48
	61	Cortland	Howard	7.5	40.3	1.2	1009	347	320	74	45
			Average	6.6	26.3	4.2	755	287	297	62	38

† Trials were categorized into four groups based on yield response to N: (1) no response to N (MERN = 0; 19 trials), (2) no yield plateau (MERN > 135 kg N ha^{-1}; one trial), (3) a yield plateau between 0 and the lowest N rate (34 kg N ha^{-1}; seven trials), and (4) a yield plateau between the lowest and highest N rates (35 trials).
‡ KCl extractable NO_3-N and NH_4-N (Keeny and Nelson, 1982).
§ Permanganate-oxidizable carbon (Weil et al., 2003).
¶Illinois Soil N Test. Direct-diffusion procedures with the enclosed griddle modification (Khan et al., 2001).
#LOI: loss on ignition; SOM: soil organic matter. Soil was dried at 105°C, weighed, and ashed for two hours at 500°C.

Table 4.2. Baseline soil nutrients for 62 forage winter cereal N rate trials in New York conducted from 2013 to 2016. Values are averages of 20 soil composites (each containing eight, 0- to 20-cm cores) within each field. The Cornell Morgan soil test method (Morgan, 1941) was used for all nutrients.

Group†	Tri	County	Soil series	P‡	K‡	Mg‡	Ca	Al	Mn	Zn	B	Fe
				mg kg^{-1}								
1	5	Oneida	Lima	5.0 (H)	72 (H)	131 (VH)	1296	18.1	20.3	0.1	0.1	1.7
	6	Rensselaer	Rhinebeck	5.7 (H)	78 (H)	123 (VH)	822	12.8	29.6	1.1	0.1	1.3
	7	St.	Hogansbur	2.3 (M)	98 (H)	132 (VH)	1155	41.8	15.4	0.7	0.2	2.7
	10	Clinton	Hailesboro	22.5 (VH)	171 (VH)	689 (VH)	3317	11.3	17.5	1.7	0.7	3.2
	15	Wyoming	Erie	10.3 (VH)	114 (VH)	215 (VH)	1962	18.1	26.8	0.8	0.3	2.6
	17	Yates	Lansing	7.3 (H)	87 (VH)	136 (VH)	1381	10.7	20.0	0.3	0.2	1.4
	18	Genesee	Cazenovia	22.7 (VH)	181 (VH)	202 (VH)	2045	6.4	26.7	1.2	0.5	1.2
	21	Genesee	Lima	48.4 (VH)	98 (VH)	271 (VH)	1907	6.7	27.0	1.8	0.7	1.7
	23	Wyoming	Conesus	24.1 (VH)	118 (VH)	300 (VH)	2293	3.7	30.1	1.2	0.8	1.2
	24	Livingston	Howard	12.2 (VH)	168 (VH)	184 (VH)	1137	14.0	37.9	0.8	0.2	1.8
	27	Wyoming	Allard	21.2 (VH)	94 (H)	233 (VH)	1327	31.6	23.3	2.3	0.2	2.3
	30	Steuben	Howard	1.3 (L)	80 (H)	268 (VH)	1344	34.1	58.1	0.3	0.1	3.2
	31	Steuben	Howard	19.8 (VH)	185 (VH)	183 (VH)	991	28.6	27.1	0.8	0.1	2.8
	37	Madison	Mardin	3.8 (M)	86 (H)	121 (VH)	1436	41.8	28.7	0.6	0.2	2.7
	48	Jefferson	Collamer	8.5 (H)	123 (VH)	201 (VH)	2170	13.9	18.4	2.0	0.5	1.8
	49	St.	Swanton	14.5 (VH)	143 (VH)	265 (VH)	1480	15.1	13.1	1.1	0.4	1.9
	52	Clinton	Bombay	1.7 (L)	25 (VL)	77 (H)	1198	25.7	14.6	0.3	0.2	3.1
	60	Cortland	Tioga	64.5 (VH)	328 (VH)	420 (VH)	3241	10.5	30.4	3.0	0.7	1.7
	63	Wayne	Hilton	5.0 (H)	56 (M)	110 (H)	1477	9.6	32.4	0.5	0.3	1.2
			Group average	15.8	121	224	1683	18.7	26.2	1.1	0.3	2.1

Table 4.2 (Continued)

Group	Tria	County	Soil series	P‡	K‡	Mg‡	Ca	Al	Mn	Zn	B	Fe
				mg kg^{-1}								
2	4	Oneida	Lima	5.5 (H)	73 (H)	179 (VH)	1559	23.6	34.4	0.3	0.1	2.0
3	1	Cortland	Howard	98.9 (VH)	477 (VH)	372 (VH)	2249	14.3	37.4	4.8	0.6	2.3
	3	Delaware	Tunkhanno	36.6 (VH)	123 (VH)	182 (VH)	1685	23.6	32.5	2.9	0.2	3.0
	44	Chenango	Unadilla	2.3 (M)	63 (H)	168 (VH)	968	61.2	10.1	1.2	0.1	3.6
	46	Madison	Palmyra	2.8 (M)	37 (L)	376 (VH)	4074	4.5	44.6	0.6	0.7	1.0
	50	St. Lawrence	Grenville	26.1 (VH)	179 (VH)	354 (VH)	1683	7.9	16.1	1.1	0.7	1.2
	53	Wyoming	Appleton	13.0 (VH)	118 (VH)	216 (VH)	1615	10.8	18.9	0.4	0.4	1.7
	62	Cortland	Howard	18.9 (VH)	189 (VH)	235 (VH)	2824	13.8	14.7	2.0	0.5	1.5
			Group average	28.4	171	272	2157	19.4	24.9	1.9	0.5	2.0
4	2	Cortland	Lordstown	6.3 (H)	85 (H)	1611 (VH)	1753	24.5	10.9	0.7	0.3	2.3
	8	St. Lawrence	Swanton	26.4 (VH)	106 (H)	305 (VH)	1835	7.0	24.4	1.4	0.5	2.0
	9	Clinton	Shaker	4.0 (M)	42 (L)	63 (H)	704	33.9	21.7	0.7	0.1	4.7
	11	Jefferson	Kingsbury	64.7 (VH)	430 (VH)	442 (VH)	2891	8.7	30.8	3.1	0.8	3.8
	12	Jefferson	Hinkley	2.1 (M)	68 (M)	92 (H)	1440	44.0	4.2	0.9	0.3	2.0
	13	Lewis	Nellis	6.1 (H)	84 (H)	198 (VH)	3044	7.2	29.3	1.0	0.7	1.4
	14	Genesee	Palmyra	7.4 (H)	169 (VH)	121 (VH)	1855	10.3	28.5	0.4	0.3	2.1
	16	Livingston	Valois	13.0 (VH)	138 (VH)	295 (VH)	2178	8.3	25.4	0.8	0.5	1.0
	19	Ontario	Honeoye	12.4 (VH)	128 (VH)	212 (VH)	1538	12.9	41.2	0.6	0.3	1.0
	20	Orleans	Madrid	7.3 (H)	163 (VH)	162 (VH)	1138	14.7	24.3	0.5	0.2	1.3

Table 4.2 (Continued)

Group	Tria	County	Soil series	P‡	K‡	Mg‡	Ca	Al	Mn	Zn	B	Fe
				----------	----------	----------	----------	mg kg^{-1}	----------	----------	----------	----------
4	22	Wyoming	Conesus	9.4 (H)	97 (VH)	282 (VH)	2168	7.4	29.6	0.8	0.5	1.1
	25	Livingston	Copake	5.9 (H)	87 (H)	148 (VH)	1063	9.3	25.0	0.5	0.2	1.1
	26	Orleans	Hilton	4.4 (H)	40 (M)	372 (VH)	1588	11.8	26.8	1.9	0.5	1.4
	28	Ontario	Ontario	9.9 (VH)	44 (M)	130 (VH)	1038	24.0	14.3	1.0	0.3	2.8
	29	Steuben	Alton	35.1 (VH)	182 (VH)	211 (VH)	2228	14.4	21.6	1.3	0.4	2.4
	33	Tompkins	Bath	10.6 (VH)	222 (VH)	225 (VH)	2426	35.2	21.9	1.7	0.3	3.7
	34	Cortland	Tioga	3.1 (M)	110 (VH)	101 (VH)	919	45.0	34.3	3.5	0.2	3.2
	35	Cortland	Valois	9.9 (VH)	184 (VH)	225 (VH)	2674	15.0	20.0	0.7	0.4	1.5
	36	Cortland	Chagrin	5.0 (H)	74 (H)	185 (VH)	1582	15.6	15.5	0.8	0.7	1.4
	38	Madison	Howard	6.1 (H)	160 (VH)	148 (VH)	1578	26.4	18.3	0.4	0.2	2.1
	39	Madison	Raynham	10.5 (VH)	79 (H)	200 (VH)	1449	13.7	33.3	0.7	0.3	1.6
	40	Madison	Palmyra	22.5 (VH)	90 (H)	305 (VH)	2795	7.3	10.3	0.6	0.5	1.6
	41	Chemung	Unadilla	2.6 (M)	40 (M)	193 (VH)	1145	32.0	31.5	0.5	0.1	3.4
	42	Tioga	Middlebury	28.8 (VH)	87 (H)	281 (VH)	1881	11.2	20.3	0.8	0.3	1.2
	43	Chenango	Chenango	8.5 (H)	146 (VH)	145 (VH)	1202	31.8	51.3	2.1	0.2	2.4
	45	Chenango	Howard	8.3 (H)	153 (VH)	147 (VH)	1215	33.1	53.6	2.2	0.2	2.5
	47	Oneida	Appleton	12.4 (VH)	146 (VH)	291 (VH)	2405	4.1	26.6	0.6	0.8	1.2
	51	Clinton	Malone	4.1 (M)	113 (H)	156 (VH)	958	13.8	24.6	0.6	0.2	2.3
	54	Wyoming	Appleton	7.9 (H)	117 (VH)	175 (VH)	1228	9.7	20.0	0.5	0.3	1.1

Table 4.2 (Continued)

Group	Tria	County	Soil series	P‡	K‡	Mg‡	Ca	Al	Mn	Zn	B	Fe
				mg kg^{-1}								
4	55	Delaware	Unadilla	11.6 (VH)	115 (VH)	134 (VH)	839	13.4	19.5	0.5	0.2	1.5
	56	Delaware	Tunkhannock	10.3 (VH)	54 (M)	159 (VH)	2008	30.2	18.8	0.7	0.5	2.1
	57	Montgomery	Nunda	4.6 (H)	95 (VH)	247 (VH)	2134	8.1	15.5	0.3	0.3	1.5
	58	Montgomery	Burdett	5.4 (H)	75 (H)	166 (VH)	2801	6.5	12.7	0.3	0.5	1.6
	59	Cortland	Howard	32.4 (VH)	256 (VH)	287 (VH)	2968	10.3	16.6	1.2	0.7	1.7
	61	Cortland	Howard	31.3 (VH)	165 (VH)	332 (VH)	3294	7.5	20.3	2.6	0.8	2.4
			Group average	12.9	124	208	1827	17.4	24.1	1.1	0.4	2.0

† Trials were categorized into four groups based on yield response to N: (1) no response to N (MERN = 0; 19 trials), (2) no yield plateau (MERN > 135 kg N ha^{-1}; one trial), (3) a yield plateau between 0 and the lowest N rate (34 kg N ha^{-1}; seven trials), and (4) a yield plateau between the lowest and highest N rates (35 trials).
‡ Soil test P, K, and Mg categorized as low (L), medium (M), high (H), or very high (VH) according to soil fertility interpretations of Cornell University (Cornell Univ. Cooperative Extension, 2016).

Plot Management and Harvest

All studies were sown in the fall under farmer management. Farmers chose the winter cereal species, seeding rate, seeding depth, row spacing, fall fertilization, and planting date. Planting dates ranged from 30 August to 20 October, seeding rates from 67 to 207 kg ha^{-1}, and row spacings from 18 to 20 cm. Previous crops included corn, legumes, sorghum [*Sorghum bicolor* (L.) Moench.] × sudangrass (*Sorghum sudanense* Piper), sorghum, small grains, potatoes (*Solanum tuberosum* L.), and fallow. Planting methods included conventional drill, no-till drill, broadcast, and AerWay® (Salford Group, Inc., Osceola, IA) seeding (includes soil aeration followed by seeding). Field histories were collected from each farmer, and included information such as effective soil drainage, soil series and soil management group (SMG), planting information, past management practices, and fertilizer and/or manure applications. Manure applications the previous fall and the previous summer were recorded separately, but because manure analyses were not available for individual applications, total N applied with past manure applications could not be determined reliably. Soil hydrologic groups (HG) of A or B were classified as well-drained, and HGs of C or D were classified as poorly-drained.

Many sites did not have reliable weather stations nearby, so total precipitation, daily temperatures, and growing degree days (GDD) could not be determined. Instead, elevation above sea level and plant hardiness zones were used. Plant hardiness zones were characterized by the average minimum annual temperature of a location. Trials were located in plant hardiness zones 7 through 11, with 1, 8, 15, 28, and 10 trials in zones 7, 8, 9, 10, and 11, respectively (USDA Plant Hardiness Zone Map, 2012).

Plots were harvested when the cereals reached the flag-leaf stage (Feekes stage 9; Zadoks et al., 1974) in May of each year. Harvest dates ranged from 5 May to 29 May. Yield was determined by hand-harvesting three 99 x 20 cm frames at a 10 cm harvest height above the ground.

Soil and Forage Analysis

Soil samples were dried at 50°C, ground to pass through a 2-mm screen, and submitted for baseline fertility analysis. At the Analytical Laboratory and Maine Soil Testing Service (Orono, ME), soil pH was measured in a 1:1 (w/v) water extract and SOM was determined by loss-on-ignition through exposure to 500°C (Storer, 1984). Soil pH ranged from 5.7 to 7.5, acceptable for winter cereals. The Cornell Morgan test was used to extract soil P, K, Mg, Ca, Mn, and Zn by shaking dried samples in a 1:5 (v/v) ratio for 15 min in Morgan solution (1 M sodium acetate buffered at pH 4.8; Morgan, 1941). The extracts were filtered through a Whatman no. 2 equivalent filter paper following procedures outlined in NEC-1012 (Northeast Coordinating Committee for Soil Testing, 2011). The filtered extracts were analyzed for K, Mg, Ca, Mn, and Zn using an inductively coupled plasma atomic emission spectrometer (ICP-AES, JY70 Type II, Jobin Yvon, Edison, NY). Phosphorus was determined colorimetrically using the ammonium molybdate-ascorbic acid method (Knudsen and Beegle, 1988) with a Lachat QuikChem 8000 flow injection analyzer (Lachat Instruments, Milwaukee, WI). According to soil fertility interpretations of Cornell University (Cornell Univ. Cooperative Extension, 2016), initial soil test P was low, medium, high, and very high for 2, 9, 21, and 31 of the trials, respectively. Soil test K was very low, low, medium, high, and very high for 1, 2, 5, 20, and 35 of the trials, respectively.

Soil samples were also submitted to the Nutrient Management Spear Program Laboratory and analyzed for 2 M KCl extractable NO_3-N and NH_4-N (Keeny and Nelson, 1982) and Illinois Soil N Test (ISNT)-N by direct-diffusion procedures with 2 M NaOH as described in Khan et al. (2001) with the enclosed griddle modification (Klapwyk and Ketterings, 2005). The ISNT-N values were not adjusted for ammonium content, so data represent both ammonium and amino sugar N content. Permanganate-oxidizable carbon (active C) was measured with a spectrophotometer (Aquamate VIS, Thermo Fisher Scientific, Waltham, MA) as described in Weil et al. (2003). Percent loss on ignition (LOI) was determined by drying the soil at 105°C for moisture content determination followed by ashing for two hours at 500°C.

Forage samples were dried at 55°C and ground to pass through a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ). Samples were analyzed for fiber content and digestibility by the Cherney laboratory at Cornell University (Ithaca, NY). Neutral detergent fiber (aNDF) was analyzed according to Van Soest et al. (1991) including sodium-sulfite using the ANKOM system (ANKOM Technology, Fairport, NY). In vitro 48-h fiber digestibility ($NDFD_{48}$) was determined according to ANKOM procedures described by Valentine et al. (2018) using the Daisy II$^{200/220}$ incubator (ANKOM Technology, Fairport, NY). Ruminal fluid inoculum was collected from a non-lactating, rumen-fistulated Holstein cow (*Bos taurus*) fed a medium quality hay diet ad libitum. Samples were incubated in F57 ANKOM digestion bags for 48 h at 39°C. Undigested residues were extracted with neutral detergent solution.

Forage samples were also submitted to Brookside Laboratories, Inc. (New Bremen, OH.) for total forage C and N content determined by combustion analysis using an element analyzer (Vario El Cube, Elementar, Germany). Total forage N was multiplied by 6.25 to determine crude protein (CP) concentration according to the AACC standard protocol (AACC, 1999, Method 46-10.01).

Statistical Methods

The 62 trials represent a variety of soil series and management characteristics. Each trial was analyzed individually to determine the MERN at spring dormancy break for each site, following the stepwise approach presented in Lyons et al. (2018b). For N-responsive trials, the quadratic plateau model was used (Eq. 4.1) to determine the MERN (Eq. 4.2) and yield at the MERN for each trial (R Core Team, 2015):

$$E\{Y(N)\} = \begin{cases} bN + cN^2 + \mu + \frac{b^2}{4c}, N < -\frac{b}{2c} \\ \mu, N \geq -\frac{b}{2c} \end{cases} \quad [4.1]$$

$$MERN = \frac{\frac{w}{p} - b}{2c} \quad [4.2]$$

where $E\{Y(N)\}$ is the expected yield as a function of N application, N; μ is the maximum yield predicted by a linear plateau model (Mg DM ha^{-1}); b is the linear coefficient; c is the quadratic coefficient; p is the forage value (\$198.42 Mg^{-1} DM); and w is the cost of fertilizer (\$1.26 kg^{-1} N). The intercept is the average value of the yield at the 0 kg N ha^{-1} treatment, and –b/2c was constrained to equal μ (Lyons et al., 2018b). The yield at the MERN is the corresponding yield value for the calculated MERN. This approach reflects the need for feedback on MERNs and yields of individual fields for participating farmers and for collaborative, on-farm, research networks (Lyons et al., 2018b).

After evaluation of various approaches (including various regression analyses and logistic models), to predict MERN and yield at MERN across sites, regression tree analysis was determined to be most appropriate for the type of data collected (Johnson, 2017). We used the tree package in R for this analysis (R Core Team, 2015; Ripley, 2016) and included all possible predictor variables including soil fertility parameters and soil series, management practices including manure history and planting date, species, and plant hardiness zone. Only trials with a MERN of 0 or, for responsive trials, an $R^2 \geq 0.7$ for the quadratic plateau yield response curve, were included in the regression tree analysis (*n* = 37). All other trials either did not have a MERN (1 trial), had a MERN < 34 kg N ha^{-1} (7 trials) or were highly variable among replications and rates ($R^2 < 0.7$; 17 trials). Each trial included in the regression tree analysis represented a single data point in the form of MERN or yield at the MERN for the response variable. The response variable (MERN) was defined by two categories: a MERN of 0 and a positive MERN, defined as 67 to 101 kg N ha^{-1}, reflecting the typical response range if a trial was responsive to N addition in the spring. PROC MIXED of SAS (SAS Institute, 1999) was used to detect treatment differences in forage yield and quality.

RESULTS AND DISCUSSION

MERN and Yield

The MERNs for the 62 trials ranged from 0 to more than 135 kg N ha^{-1} (Table 4.3; Figure 4.1). Yield responses fell into four groups: (1) no response to N (MERN = 0; 19 trials), (2) no yield plateau (MERN > 135 kg N ha^{-1}; one trial), (3) a yield plateau between 0 and the lowest N rate (34 kg N ha^{-1}; seven trials), and (4) a yield plateau between the lowest and highest N rates (35 trials) (Table 4.3). The MERNs for the fourth group ranged from 47 to 112 kg N ha^{-1}, averaging 77 kg N ha^{-1}.

Table 4.3. Most economic rate of N (MERN), yield at the MERN, and N uptake (forage N content above a 10.2 cm harvest height) at the MERN for 62 forage winter cereal N rate trials in New York conducted from 2013 to 2016. The MERNs were determined using a quadratic plateau model.

Group†	Trial	Species	MERN	$Yield_{MERN}$	N $uptake_{MERN}$
			kg N ha^{-1}	Mg DM ha^{-1}	kg N ha^{-1}
1	5	Triticale	0	4.2	69
	6	Triticale	0	5.6	97
	7	Triticale	0	3.7	51
	10	Cereal rye	0	2.6	64
	15	Triticale	0	4.4	85
	17	Cereal rye	0	4.9	69
	18	Triticale	0	5.6	154
	21	Triticale	0	4.5	77
	23	Triticale	0	5.0	62
	24	Triticale	0	6.0	132
	27	Triticale	0	4.6	68
	30	Triticale	0	3.2	59
	31	Triticale	0	6.2	96
	37	Wheat	0	1.0	9
	48	Cereal rye	0	4.2	77
	49	Cereal rye	0	2.8	62
	52	Cereal rye	0	2.6	54
	60	Triticale	0	3.2	49
	63	Triticale	0	6.9	109
		Average	0	4.3	76
2	4	Triticale	> 135	5.8‡	156‡
3	1	Triticale	< 34	5.4	143
	3	Cereal rye	< 34	2.7	60
	44	Cereal rye	< 34	1.6	39
	46	Cereal rye	< 34	1.8	39
	50	Cereal rye	< 34	3.1	70
	53	Triticale	< 34	3.4	86
	62	Triticale	< 34	1.6	42
		Average	< 34	2.8	68
4	2	Triticale	75	2.2	67
	8	Triticale	48	6.0	110
	9	Cereal rye	81	3.8	111
	11	Triticale	68	4.9	124
	12	Triticale	73	2.5	51
	13	Triticale	47	3.8	109
	14	Triticale	72	4.0	92
	16	Triticale	90	6.3	133
	19	Triticale	84	6.5	154
	20	Triticale	81	4.9	77
	22	Triticale	88	4.9	135
	25	Triticale	75	2.9	62
	26	Triticale	102	4.9	128
	28	Triticale	93	3.1	99
	29	Triticale	89	5.8	114
	33	Triticale	61	2.9	68
	34	Wheat	83	2.9	69
	35	Wheat	105	3.6	99

Table 4.3 (Continued)

Group	Trial	Species	MERN	$Yield_{MERN}$	N $uptake_{MERN}$
			kg N ha^{-1}	Mg DM ha^{-1}	kg N ha^{-1}
4	36	Triticale	89	3.6	92
	38	Cereal rye	83	4.0	110
	39	Cereal rye	63	5.2	123
	40	Cereal rye	83	2.2	55
	41	Cereal rye	99	5.4	149
	42	Triticale	76	6.9	146
	43	Cereal rye	112	5.2	121
	45	Cereal rye	49	3.6	72
	47	Triticale	70	4.3	76
	51	Cereal rye	67	4.0	105
	54	Triticale	48	5.2	155
	55	Cereal rye	95	4.5	112
	56	Cereal rye	74	3.8	118
	57	Cereal rye	57	3.4	76
	58	Cereal rye	58	2.2	59
	59	Triticale	60	3.1	100
	61	Triticale	101	3.1	77
		Average	77	4.2	101

†Trials were categorized into four groups based on yield response to N: (1) no response to N (MERN = 0; 19 trials), (2) no yield plateau (MERN > 135 kg N ha^{-1}; one trial), (3) a yield plateau between 0 and the lowest N rate (34 kg N ha^{-1}; seven trials), and (4) a yield plateau between the lowest and highest N rates (35 trials).
‡A yield plateau was not reached, therefore no MERN could be determined. The average value of the highest N rate is reported.

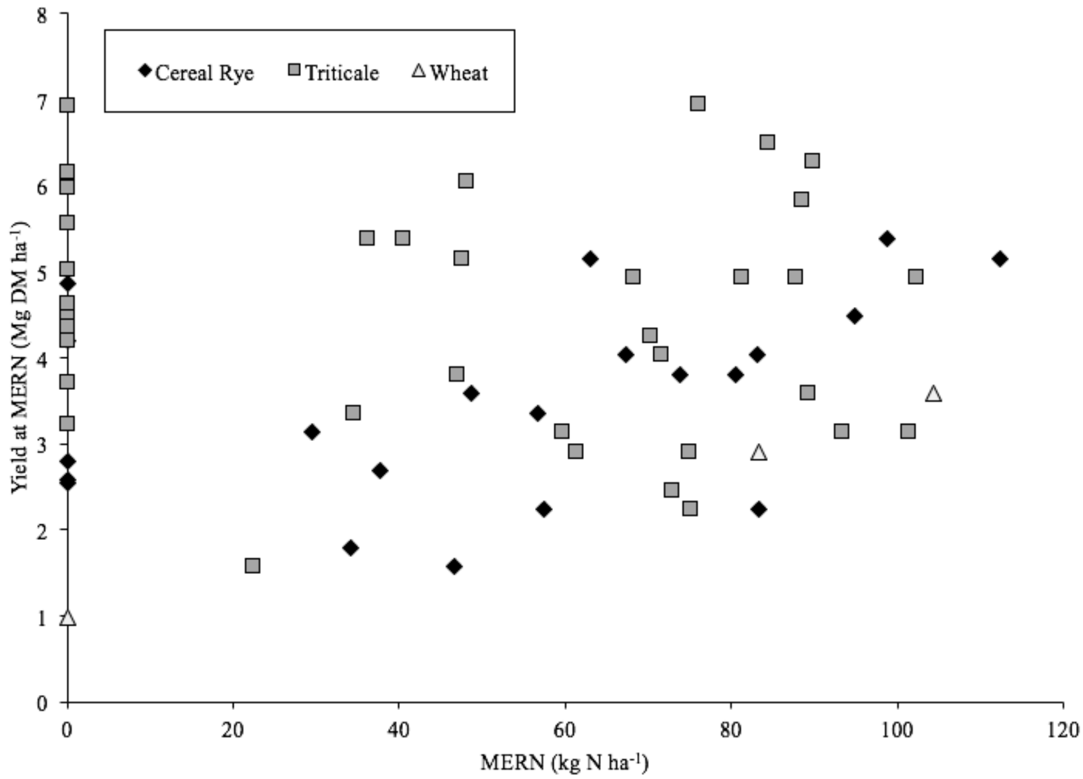

Figure 4.1. Winter cereal most economic rates of N (MERN) and yields at the MERN for 62 N rate trials from 2013 to 2016. Fertilizer N was applied at dormancy break in the spring and plots were harvested at flag-leaf stage (Feekes stage 9; Zadoks et al., 1974) in May.

Yield at the MERN for the trials in group 1 ranged from 1.0 to 6.9 Mg DM ha^{-1}, averaging 4.3 Mg DM ha^{-1} (Table 4.3). With the exception of trials 17 and 30, all other group 1 trials had manure applied the previous year (summer or fall). These results are consistent with another study in New York (Ketterings et al., 2007), where BMR sorghum × sudangrass required 40 to 60 kg N ha^{-1} (at most) following a recent manure application as compared to 125 to 145 kg N ha^{-1} without manure N. Although the study by Ketterings et al. (2007) was done with a warm-season crop, it is likely that past manure applications at typical rates in New York will also meet the crop N needs of winter cereals. Two of the trials in group 1 had low soil test P (trials 30 and 52) and one had very low soil test K (trial 52) at the start of the trial, which could have impacted the response to N at these locations. However, the yields at the MERN for these trials were well within the range of others in this group (3.2 and 2.6 Mg DM ha^{-1} for trials 30 and 52, respectively), so soil P or K may not have been a yield-limiting factor. This may have been because these winter cereals have low demands for both P and K (Mahler, 2007).

The trial in group 2 (trial 4) had a maximum yield of 5.8 Mg DM ha^{-1}. Trial 4 did not have manure applied over the previous year, was relatively high yielding compared to the other groups (5.8 Mg DM ha^{-1} maximum yield vs. 4.3, 2.8, and 4.2 Mg DM ha^{-1} average yields for groups 1, 3, and 4, respectively), and had the highest N uptake of all trials (156 kg N ha^{-1}). Thus, this trial was particularly responsive to additional N.

The seven trials in group 3 had yields at the MERN ranging from 1.6 to 5.4 Mg DM ha^{-1}, averaging 2.8 Mg DM ha^{-1}. All trials in group 3 were planted after the recommended planting time in the Northeast of mid- to late-September. Late planting could have led to a disadvantage in establishment for trials in group 3, thus hindering spring growth (Lyons et al., 2018a). The average yield at the MERN for group 3 trials was lower than the other groups (2.8 Mg DM ha^{-1} for group 3 compared to 4.3, 5.8, and 4.2 Mg DM ha^{-1} for groups 1, 2, and 4). One trial (trial 53) followed a legume crop, and five trials (trials 1, 3, 50, 53, and 62) received manure over the previous year, both of which could explain the low N requirement for these trials.

The remaining 35 trials (group 4) had MERNs ranging from 47 to 112 kg N ha^{-1}, averaging 77 kg N ha^{-1}, with yields at the MERN ranging from 2.2 to 6.9 Mg DM ha^{-1} with an average of 4.2 Mg DM ha^{-1}. On average, the winter cereals required 19 kg N per 1 Mg DM ha^{-1}. Similar N needs were found in another forage winter cereal study in New York, which ranged from 0 to 128 kg N ha^{-1}, averaging 88 kg N ha^{-1} for sites with positive MERNs and 20 kg N ha^{-1} per Mg DM ha^{-1} (Lyons et al., 2018a). The optimal N rates determined by Gibson et al. (2007) in Iowa were much lower than the New York studies, 33 kg N ha^{-1} for 8.9 Mg DM ha^{-1} in late May (4 kg N ha^{-1} per Mg DM ha^{-1}), although in their study the optimal N rates were determined to be the N rate above which yield did not increase as opposed to using limiting nutrient response functions and economic components. It is likely that climate and soil variations also contribute to differences in winter cereal N needs and performance between these two regions.

Across all trials, yield at the MERN ranged from 1.0 to 6.9 Mg DM ha^{-1}, with 81% of trials yielding between 2.2 and 5.8 Mg DM ha^{-1} (Figure 4.2).

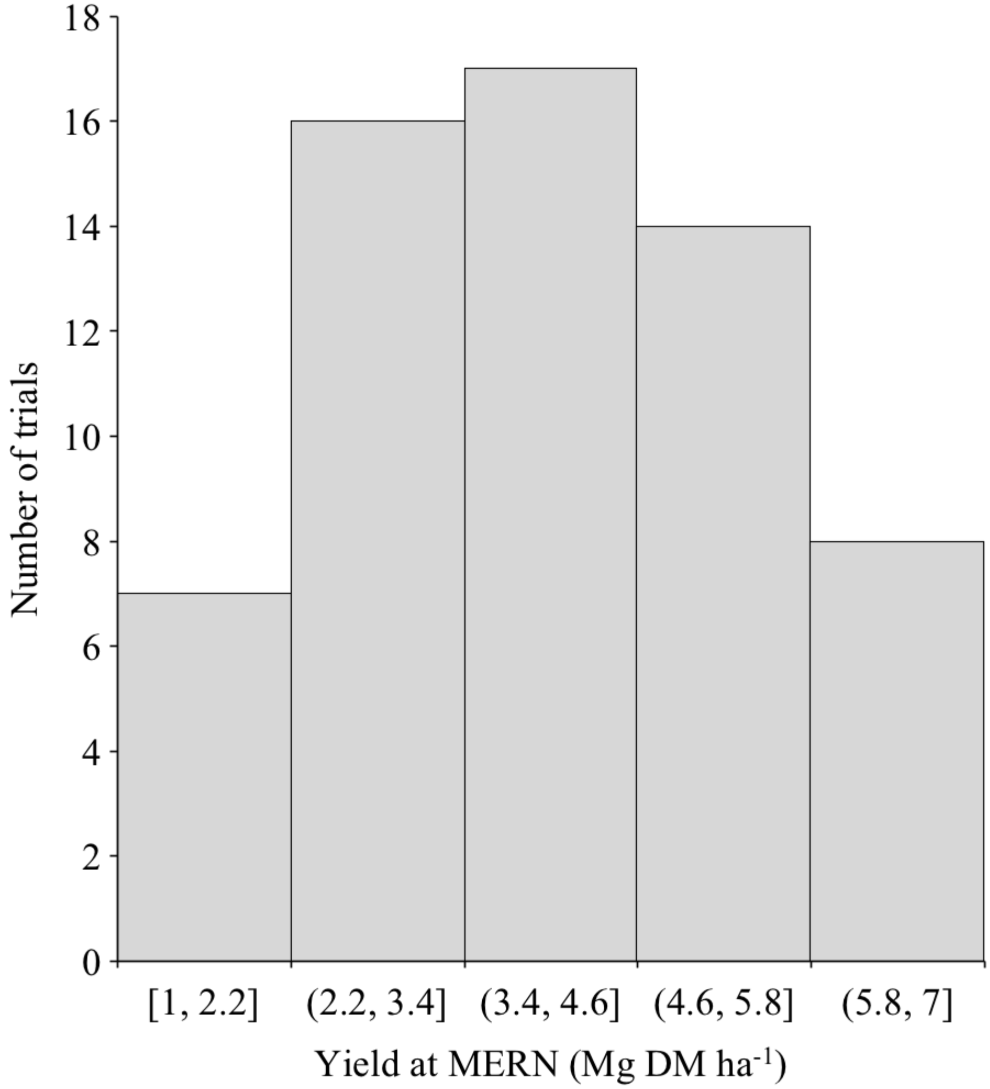

Figure 4.2. Yield at the MERN distribution for 62 forage winter cereal N rate trials in New York from 2013 to 2016. Fertilizer N was applied at dormancy break in the spring and plots were harvested at flag-leaf stage (Feekes stage 9; Zadoks et al., 1974) in May.

The study by Lyons et al. (2018a) found similar yields at the MERN for forage triticale harvested at the flag-leaf stage, ranging from 1.9 to 6.4 Mg DM ha^{-1} across various planting dates and fall N applications. Despite differences in optimum N rates, Gibson et al. (2007) also had similar forage triticale yields, which ranged from 5.5 to 10.3 Mg DM ha^{-1} when harvested between 2 May and 8 July with 33 kg N ha^{-1} applied in late March. However, it should be noted that harvest dates associated with the yields were not clearly defined in Gibson et al. (2007), and growth stage at harvest was not reported. The higher yielding triticale may have been due to a more mature growth stage at harvest.

Predicting Yield

Yield at the MERN could not accurately be predicted through regression tree analysis with the data collected. Trials 37, 44, 46, and 62 had yields at the MERN less than 2.2 Mg DM ha^{-1}, yields that may not warrant investment in fertilizer (Hanchar et al., 2015). Two of these trials (trials 44 and 62) were high or very high in soil test P and K. One of them (trial 62) had received manure in the most recent year. Trials 37 and 46 were medium in soil test P and high (trial 37) or low (trial 46) in K. Trial 37 had received manure in the most recent year. These soil test values and manure histories suggest that of the four low yielding trials, only for site 46 was soil P or K likely to have been crop yield limiting, while low yield for the other locations was most likely due to other yield limiting factors. In contrast, 83% of the higher yielding trials received manure over the past year, and 38% received manure as recent as the previous fall. All of the low-yielding trials were described by farmers as undrained, while 45% of the higher yielding trials were classified as well-drained. In addition, three of the four low-yielding trials were planted after 1 October (trials 44, 46, and 62), while 62% of the higher yielding trials were planted before this date. These observations suggest that sites with low soil fertility and poorly-drained soils that are planted late, without recent manure addition, may not yield sufficiently to warrant investment in fertilizer in the region (Hanchar et al., 2015).

Predicting the MERN

The majority (66%) of trials with a yield response to N had MERNs between 67 and 101 kg N ha^{-1}. Thus, this range was used to define the response variable of "positive MERN" for regression tree analysis. Farmer-reported soil drainage status, manure history, and planting date were the most important predictors of MERN (Figure 4.3). Winter cereals grown on fields characterized as well-drained did not require additional N at dormancy break (MERN = 0 kg N ha^{-1}). For the somewhat poorly or poorly drained fields, 67 to 101 kg N ha^{-1} was needed if no manure had been applied over the previous year. When manure was applied within the last year in a poorly drained field but planting took place by 1 October (early planting), no additional N was needed at dormancy break either while 67 to 101 kg N ha^{-1} was needed if planting took place after 1 October. These results are consistent with Lyons et al. (2018a) who reported that fall N inputs only benefitted spring triticale yields when planting took place by late September (20 September in that study).

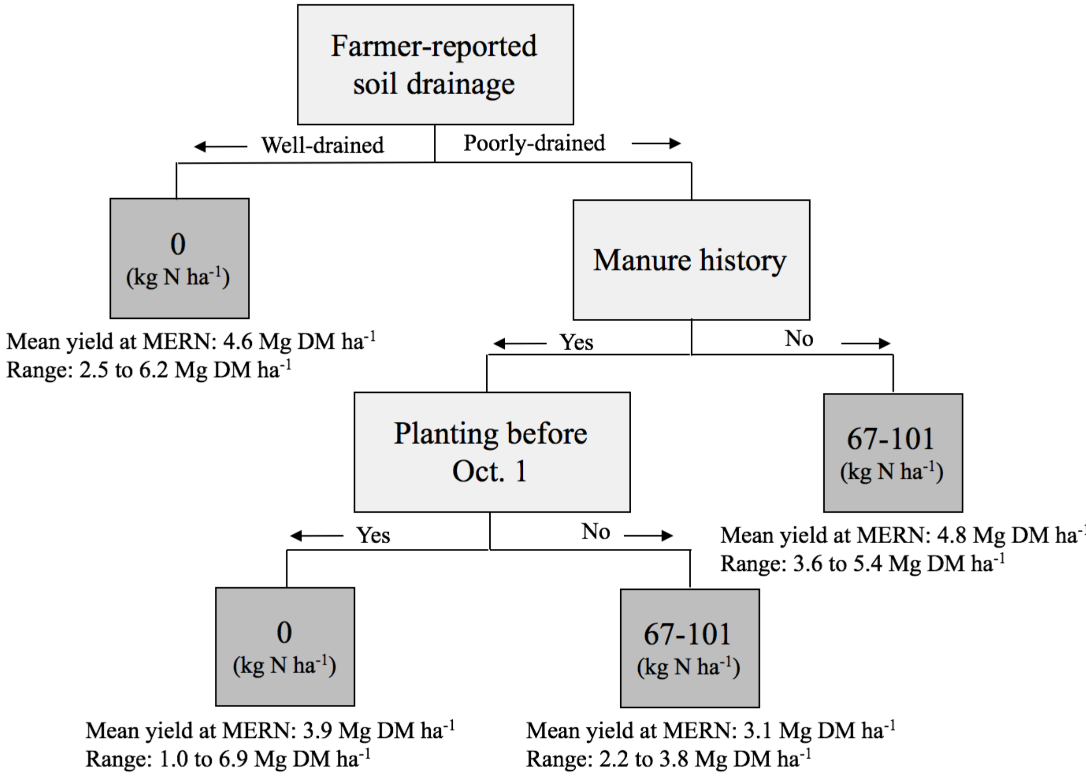

Figure 4.3. Regression tree analysis for predicting the most economic rates of N (MERN) of winter cereal N-rate trials in New York (n = 37). Predictor variables included soil fertility, management, and geographic characteristics. If the indicated statement is “true,” move to the left branch. Dark gray boxes indicate the predicted MERN. Drainage represents farmer-reported soil drainage status and manure history refers to manure applied within the last year (either fall or spring).

The misclassification error rate for MERN prediction was 22% (eight of 37 trials included in model development) (Table 4.4). Of the eight incorrectly classified trials, six trials required 67 to 101 kg N ha^{-1}, while the regression tree predicted MERNs of 0 (trials 12, 22, 39, 55, 57, and 61; Table 4.4). For three of these trials (trials 12, 22, 39), the fields were well-drained according to the farmers. Trial 39 was on a somewhat poorly-drained soil that was low in SOM content compared to the average SOM content of group 4 trials (29 vs. 38 g kg^{-1}). No manure had been applied in the previous fall, and thus reclassification as poorly drained would have resulted in a correct classification for this trial. Trial 12 (very well-drained sandy soil) and trial 22 (moderately well-drained, mid-textured soil) were indeed well-drained, but lacked a fall manure application. The SOM and ISNT-N for trials 12 (37 g kg^{-1} SOM and 289 mg kg^{-1} ISNT) and 22 (39 g kg^{-1} SOM and 298 mg kg^{-1} ISNT-N) were comparable to the group 4 averages (38 g kg^{-1} SOM and 287 mg kg^{-1} ISNT-N), and active C for both trials (919 and 836 mg kg^{-1} for trials 12 and 22, respectively) was within the range of group 4 trials (373 to 1127 mg kg^{-1}). The estimated soil N of the soil series in trial 12 (Ketterings et al., 2003), is lower than for other soils, regardless of soil drainage capacity, which could have impacted N needs for this location. These results suggest that N fertilizer can be needed for some well-drained fields, given no recent manure applications with adequate soil fertility.

Table 4.4. Most economic rate of N (MERN) predictions, recent manure history (within the last year), farmer-reported soil drainage, and planting date for 37 winter cereal trials used in a regression tree analysis.

Trial	Actual MERN	Predicted MERN	Species	Manure History†	Drainage‡	Planting Date
	--------- kg N ha^{-1}	-----------				
2	75	67-101	Triticale	Yes	Undrained	10/20/2012
5	0	0	Triticale	Yes	Drained	9/17/2012
6	0	0	Triticale	Yes	Undrained	9/15/2012
7	0	0	Triticale	Yes	Drained	9/14/2012
9	81	67-101	Cereal rye	Yes	Undrained	10/2/2012
10§	0	67-101	Cereal rye	Yes	Undrained	10/11/2012
11	68	67-101	Triticale	No	Undrained	9/15/2012
12§	73	0	Triticale	Yes	Drained	9/28/2012
15	0	0	Triticale	Yes	Drained	9/18/2012
17	0	0	Cereal rye	No	Drained	9/10/2012
18	0	0	Triticale	Yes	Drained	9/30/2012
20	81	67-101	Triticale	No	Undrained	10/12/2012
21	0	0	Triticale	Yes	Drained	9/15/2012
22§	88	0	Triticale	No	Drained	9/28/2012
23	0	0	Triticale	Yes	Drained	9/28/2012
24	0	0	Triticale	Yes	Drained	9/28/2012
25	75	67-101	Triticale	Yes	Undrained	10/15/2012
27	0	0	Triticale	Yes	Undrained	9/5/2012
30	0	0	Triticale	No	Drained	10/1/2012
31	0	0	Triticale	Yes	Drained	10/16/2012
34	83	67-101	Wheat	Yes	Undrained	10/10/2012
35	105	67-101	Wheat	Yes	Undrained	10/11/2012
36	89	67-101	Triticale	No	Undrained	10/9/2012
37	0	0	Wheat	Yes	Undrained	9/24/2012
39§	63	0	Cereal rye	Yes	Drained	9/17/2012
41	99	67-101	Cereal rye	No	Undrained	9/12/2012
43	112	67-101	Cereal rye	No	Undrained	9/30/2013
45	49	67-101	Cereal rye	Yes	Undrained	10/1/2013
48	0	0	Cereal rye	Yes	Drained	9/20/2013
49§	0	67-101	Cereal rye	Yes	Undrained	10/1/2013
52	0	0	Cereal rye	Yes	Undrained	8/30/2013
55§	95	0	Cereal rye	Yes	Undrained	9/5/2013
56	74	67-101	Cereal rye	Yes	Undrained	10/10/2013
57§	57	0	Cereal rye	Yes	Undrained	9/20/2014
60	0	0	Triticale	Yes	Undrained	9/30/2014
61§	101	0	Triticale	Yes	Undrained	9/28/2014
63	0	0	Triticale	Yes	Undrained	9/15/2015

†Manure applied during the previous year.
‡Farmer-reported soil drainage.
§Incorrect MERN prediction by the model.

The three other trials that required additional N but had predicted MERNs of 0 kg N ha^{-1} (trials 55, 57, and 61) were farmer-reported as poorly-drained, with a recent manure history, and planting before 1 October. These trials had in common low soil nitrate levels at dormancy break (1.0 to 2.4 mg NO_3-N kg^{-1}) compared to the average for group 4 of 4.2 mg NO_3-N kg^{-1}, and trials 55 and 57 did not receive manure the previous fall. In addition, trial 55 had considerably lower SOM (22 g kg^{-1}) and ISNT-N (164 mg kg^{-1}) than the group 4 average (38 g kg^{-1} SOM and 287 mg kg^{-1} ISNT-N), suggesting limited capacity to supply soil N through mineralization. Similar trials that were correctly predicted (also with low soil nitrate, undrained, planted before 1 October, and positive MERNs), did not receive manure the previous year. Thus, for some trials, manure applications to the crop prior to winter cereal establishment (within the previous year) supplied sufficient N; for others, manure application at planting of the winter cereal was needed to reduce N fertilizer needs to 0 kg ha^{-1}.

The two remaining trials that had a MERN of 0 kg N ha^{-1} but were predicted to need N (trials 10 and 49) were both planted on or after 1 October on poorly drained soils with a recent manure history. These two trials had in common relatively low yield compared to other trials (2.6 and 2.8 Mg DM ha^{-1} for trials 10 and 49, respectively, compared to 4.3 Mg DM ha^{-1} average for their group). The lower yield potentials for these sites could have impacted their N requirement and N uptake to a point where N credits from an earlier manure application were sufficient to meet the N needs of the crop.

Farmer-reported soil drainage status was a better predictor of N needs than the soil drainage characteristics associated with soil series, including SMG and HG. For

15 of the trials farmer-reported soil drainage status did not match the soil series-specific hydrologic group, reflecting implementation of artificial drainage and possibly misclassification of soil series in some fields. While soil series and drainage classifications are useful tools for nutrient management, farmer knowledge of field characteristics is also important for determining N needs for forage winter cereals.

Spring N and Forage Quality

For 31 trials (50%), aNDF was not impacted by N rate. Four of the trials (6%) had inconsistent differences in aNDF among N rates, with no significant differences in aNDF between the 0 and 135 kg N ha^{-1} treatments. For the other trials (44%), aNDF decreased with higher N rates. Across all trials, aNDF at the MERN ranged from 418 to 598 g kg^{-1} DM, averaging 516 g kg^{-1} DM.

Only 13 of the trials (21%) had differences in in vitro true digestibility (IVTD) among N rates, although for eight of these 13 trials (13% of all trials) there were no differences in IVTD between the 0 and 135 kg N ha^{-1} rates. For the other five trials, IVTD increased with N rate for four trials (trials 6, 29, 57, and 59) and decreased with N rate for one trial (trial 34). The IVTD at the MERN across all trials ranged from 81 to 94% DM with an average of 88% DM.

For ten of the trials (16%) N treatment impacted $NDFD_{48}$ but for five of these, there was no difference in $NDFD_{48}$ between the 0 and 135 kg N ha^{-1} treatments. For the remaining five trials, $NDFD_{48}$ decreased with N rate for four trials (trials 2, 26, 34, and 47) and increased with N rate for one trial (trial 59). The $NDFD_{48}$ at the MERN ranged from 67 to 84% NDF, averaging 78% NDF.

Based on these results, it is unlikely that spring N management will significantly impact aNDF, IVTD, or $NDFD_{48}$. It has been shown that these quality parameters are more likely related to maturity than N availability (Ball et al., 2001; Cazzato et al., 2011).

Spring N applications impacted CP concentration for 57 of the 62 trials (92%). The five trials with no differences in CP among N rates (trials 31, 33, 36, 38, and 42) averaged 141 g CP kg^{-1} DM. Of all trials with a MERN = 0 kg N ha^{-1}, 95% showed an increase in CP with N application. For trials with differences in CP among N rates, average CP ranged from 128 to 196 g kg^{-1} DM for the 0 and 135 kg N ha^{-1} treatments, respectively (Figure 4.4), and CP at the MERN ranged from 57 to 200 g kg^{-1} DM (Table 4.5) with an average increase of 0.5 g kg^{-1} CP per kg N^{-1} applied.

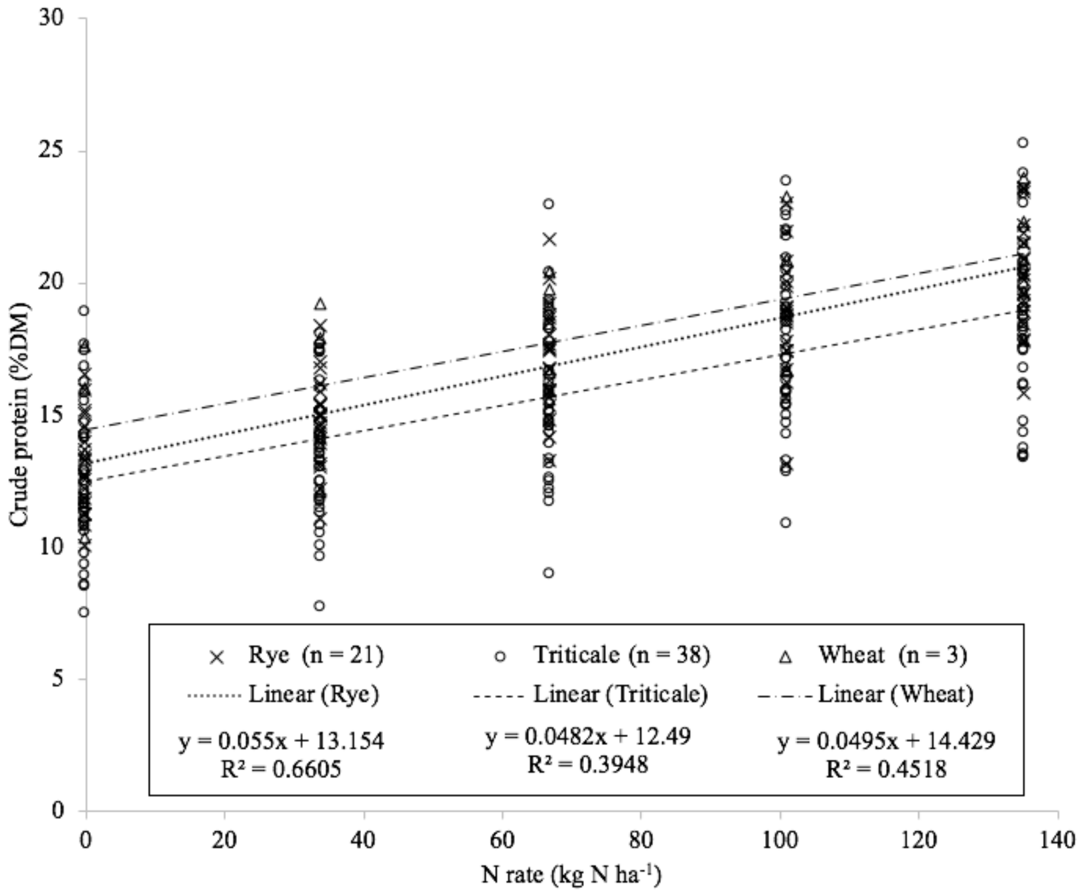

Figure 4.4. Winter cereal forage crude protein as affected by fertilizer N applied at dormancy break in the spring. Data are from 62 winter cereal N rate trials in New York from 2013 to 2016. Data represent least square means within trial.

Table 4.5. Forage quality parameters at the most economic rate of N (MERN) for 62 forage winter cereal N rate trials in New York conducted from 2013 to 2016. For sites with a MERN of 0 or with no differences between the 0 and highest N rates, values are averages across all N rates. All other values were determined at the MERN.

Group †	Trial	Species	MERN	CP‡ at MERN	aNDF‡ at MERN	IVTD‡ at MERN	$NDFD_{48}$‡ at MERN
			kg N ha^{-1}	--------- g kg^{-1}	---------	% DM	% NDF
1	5	Triticale	0	103	506	89	78
	6	Triticale	0	109	516	85	71
	7	Triticale	0	86	560	84	72
	10	Cereal rye	0	157	492	91	82
	15	Triticale	0	122	518	90	80
	17	Cereal rye	0	88	533	88	78
	18	Triticale	0	174	532	88	77
	21	Triticale	0	106	540	89	80
	23	Triticale	0	77	474	92	82
	24	Triticale	0	137	499	90	80
	27	Triticale	0	92	495	91	82
	30	Triticale	0	115	552	86	74
	31	Triticale	0	97	545	85	72
	37	Wheat	0	57	418	94	84
	48	Cereal rye	0	114	475	89	76
	49	Cereal rye	0	138	546	89	79
	52	Cereal rye	0	131	529	90	80
	60	Triticale	0	95	501	90	80
	63	Triticale	0	98	482	89	76
		Average	0	110	511	89	78
2	4	Triticale	> 135	204§	513§	87§	76§
3	1	Triticale	< 34	167	469	89	76
	3	Cereal rye	< 34	139	486	90	80
	44	Cereal rye	< 34	155	474	90	78
	46	Cereal rye	< 34	134	467	90	79
	50	Cereal rye	< 34	140	575	86	75
	53	Triticale	< 34	159	513	90	81
	62	Triticale	< 34	168	470	92	83
		Average	< 34	152	493	90	79
4	2	Triticale	75	187	427	92	80
	8	Triticale	48	114	567	81	67
	9	Cereal rye	81	182	525	87	76
	11	Triticale	68	158	492	89	78
	12	Triticale	73	130	482	91	80
	13	Triticale	47	179	462	91	80
	14	Triticale	72	143	562	88	78
	16	Triticale	90	132	573	86	75
	19	Triticale	84	148	583	85	75
	20	Triticale	81	98	560	86	75
	22	Triticale	88	171	509	90	81
	25	Triticale	75	134	492	90	80
	26	Triticale	102	162	503	90	79
	28	Triticale	93	196	480	92	83
	29	Triticale	89	122	594	82	69
	33	Triticale	61	145	498	90	79

Table 4.5 (Continued)

Group	Trial	Species	MERN	CP† at MERN	aNDF† at MERN	IVTD† at MERN	$NDFD_{48}$† at MERN
			kg N ha^{-1}	--------- g kg^{-1} ---------		% DM	% NDF
4	33	Triticale	61	145	498	90	79
	34	Wheat	83	148	500	90	79
	35	Wheat	105	172	508	90	79
	36	Triticale	89	160	492	90	80
	38	Cereal rye	83	170	513	90	80
	39	Cereal rye	63	149	560	84	72
	40	Cereal rye	83	153	499	91	82
	41	Cereal rye	99	173	561	82	69
	42	Triticale	76	131	598	82	69
	43	Cereal rye	112	146	570	82	68
	45	Cereal rye	49	126	529	87	75
	47	Triticale	70	111	521	88	75
	51	Cereal rye	67	162	543	89	80
	54	Triticale	48	188	548	86	75
	55	Cereal rye	95	156	536	89	79
	56	Cereal rye	74	194	463	91	81
	57	Cereal rye	57	141	563	87	78
	58	Cereal rye	58	166	533	88	77
	59	Triticale	60	200	508	90	80
	61	Triticale	101	153	480	90	80
		Average	77	154	524	88	77

†Trials were categorized into four groups based on yield response to N: (1) no response to N (MERN = 0; 19 trials), (2) no yield plateau (MERN > 135 kg N ha^{-1}; one trial), (3) a yield plateau between 0 and the lowest N rate (34 kg N ha^{-1}; seven trials), and (4) a yield plateau between the lowest and highest N rates (35 trials).

‡CP: Crude protein; aNDF: neutral detergent fiber; IVTD: in vitro true digestibility; $NDFD_{48}$: neutral detergent fiber digestibility (48 h).

§A yield plateau was not reached, therefore no MERN could be determined. The average value of the highest N rate is reported.

Trials with MERNs of 0 had an average CP at the MERN of 110 g kg^{-1} DM, versus 154 g kg^{-1} DM for trials with MERNs of 67 kg N ha^{-1} or greater. This suggests that some fields lacking a yield response to N addition could exhibit an increase in CP with N application. These results illustrate the importance of considering CP when developing a N management system for winter cereals grown for forage. Consistent with these findings, a 3-location triticale study by Lyons et al. (2018a) in New York found higher CP with increasing N rates for sites ranging in MERN from 0 to 128 kg N ha^{-1}, with CP increasing from 98 to 159 g kg^{-1} with N rates ranging from 0 to 135 kg spring N ha^{-1}, respectively. This 3-location study also suggested an average increase of 0.5 g kg^{-1} CP per kg N^{-1} applied.

Spring N and Residual Soil N at Harvest

For the seven trials that were evaluated for soil N at harvest in 2015 and 2016 (trials 57 through 63), there were no differences in soil ammonium-N at harvest among N rates ($P > 0.05$). However, six of the seven trials had differences in soil nitrate-N at harvest among N rates (Table 4.6) with a similar trend for the 7th trial (trial 61; $P = 0.1092$).

Table 4.6. The most economic rate of N (MERN), yield at the MERN, and nitrate-N (NO_3-N) values at green-up and harvest for seven winter cereal N rate trials from 2015 to 2016. Within each trial, different letters indicate significant differences.

Trial	MERN	Yield at MERN	NO_3-N at dormancy break	NO_3-N at harvest at MERN
	kg N ha^{-1}	Mg DM ha^{-1}	mg NO_3-N ha^{-1}	mg NO_3-N ha^{-1}
57	57	3.4	2.4	5.6
58	58	2.2	4.7	16.7
59	60	3.1	8.6	8.9
60	0	3.2	7.6	9.5
61	101	3.1	1.2	5.2
62	< 34	1.6	6.5	7.2
63	0	6.9	2.2	1.7

	NO_3-N at harvest Spring N rate (kg N ha^{-1})									
Trial	0		34		67		101		135	
	---------- mg NO_3-N ha^{-1} ----------									
57	5.1	b	4.8	b	6.0	b	8.5	ab	13.2	a
58	6.3	c	9.5	c	19.9	bc	23.3	b	42.5	a
59	7.9	b	8.2	b	9.1	ab	18.6	a	18.3	a
60	9.5	b	8.9	b	9.5	b	12.5	b	22.4	a
61	4.8	a	4.6	a	4.6	a	5.2	a	5.6	a
62	7.6	b	7.0	b	14.0	ab	22.7	ab	35.5	a
63	1.7	b	1.4	b	1.7	b	2.6	ab	3.5	a

On average across all seven trials, residual soil nitrate-N ranged from 6.1 to 20.1 mg kg^{-1} for the 0 and 135 kg N ha^{-1} treatments, respectively. At the MERN, residual soil nitrate-N ranged from 1.7 to 16.7 mg ha^{-1}, averaging 7.8 mg ha^{-1}. For the two trials that had yields at the MERN of 2.2 Mg DM ha^{-1} or less (trials 58 and 62), residual nitrate-N was higher than for those trials with higher yields. The trial that had the highest yield at the MERN (6.8 Mg DM ha^{-1}; trial 63) had the lowest residual nitrate-N at harvest for all N rates even though the MERN for this site was 0 kg N ha^{-1}. This suggests that residual soil nitrate-N at harvest is directly related to yield; the higher the yield the lower residual soil nitrate-N at harvest. Although the study by Krueger et al. (2012) did not compare soil nitrate-N to yield, soil nitrate-N was reduced in the spring at both 0-5 cm and 5-15 cm depths when cereal rye was included in a double crop rotation as compared to a corn silage monocrop (no winter cereal present). They suggested that N fertilization of a corn crop following a winter cereal is necessary due to reduced soil inorganic N. Our results suggest that fertilizing corn according to recommended rates would be necessary if a winter cereal achieved optimal yields, while less N may be needed if a winter cereal yields poorly. Additional trials are needed to test this hypothesis.

CONCLUSIONS

Forage winter cereals yielded between 1.0 and 6.9 Mg DM ha^{-1} at the MERN. Yield at the MERN could not reliably be predicted, but trials that yielded less than 2.2 Mg DM ha^{-1} lacked sufficient soil drainage, did not have recent manure applications, and were planted later in the season. The MERNs for the forage winter cereals ranged from 0 to more than 135 kg N ha^{-1}, averaging 77 kg N ha^{-1} for trials with MERNs > 0 kg N ha^{-1}. Soil drainage status, presence or absence of recent manure applications, and planting date (before or after 1 October) were most useful for predicting the MERN. Nitrogen fertilizer addition at spring dormancy break is not recommended for forage winter cereals on well-drained soils, or with recent manure histories and planting by 1 October. For sites with poorly-drained soils, 67 to 101 kg N ha^{-1} at spring dormancy break is recommended with no recent manure additions, or with recent manure additions and planting after 1 October. Some fields planted after 1 October may also require less N due to lower yield potential. While N management did not greatly impact forage fiber and digestibility, CP increased with N addition beyond the rate that optimized yield. We conclude that winter cereals grown for forage on well-drained soils, with recent manure applications, and planting before 1 October, may not need additional N at dormancy break, while approximately 19 kg N ha^{-1} per Mg DM ha^{-1} is needed for all other situations. Additional N may be added also to achieve higher forage CP. More research is needed to determine recommendations based on GDD and/or specific amounts of N applied in past manure applications.

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CHAPTER 5: NITROGEN MANAGEMENT OF BRACHYTIC DWARF BROWN MIDRIB FORAGE SORGHUM IN NEW YORK[1]

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ABSTRACT

Forage sorghum (*Sorghum bicolor* (L.) Moench) can be an alternative to corn silage (*Zea mays* L.) in the northeastern United States due to its drought tolerance and later planting date. Our objective was to determine the most economic rate of N (MERN) for a brachytic dwarf brown midrib (BMR) forage sorghum cultivar based on 13 N-rate trials in New York from 2013 to 2017. Trials fell into one of three groups based on yield response to N: group 1, no response (MERN = 0; *n* = 2), group 2, no yield plateau (*n* = 4), and group 3, yield plateau between the lowest and highest N rates (*n* = 7). Group 1 dry matter (DM) yields averaged 18.7 Mg DM ha^{-1} and included trials with manure or legume histories. Trials in group 2 averaged 17.6 Mg DM ha^{-1} at the highest N rate with an increase of 38 kg DM per kg of N. Group 3 trial MERNs

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averaged 203 kg N ha^{-1} with a yield at the MERN of 19.9 Mg DM ha^{-1}. Nitrogen use efficiency (NUE), apparent N recovery (ANR), and crude protein (CP) at the MERN of the group 3 trials averaged 46 kg DM kg^{-1} N, 63%, and 80 g kg^{-1}, respectively. Nitrogen did not greatly influence other nutritive value indicators. We conclude that the MERN of BMR forage sorghum is approximately 10 kg N per 1 Mg DM yield. Additional trials are needed to confirm that fields with recent manure or legume histories may not require additional N.

INTRODUCTION

Forage crop production in the northeastern United States is primarily for dairy systems, and typically includes corn silage rotated with alfalfa (*Medicago sativa* L.) and grass mixtures every three to four years. Having only one main crop per year during the corn silage years poses a potential risk for reduced yields in the case of drought or delayed planting. Having an alternative silage crop that could be used in such conditions would increase the resiliency of dairy cropping systems in this region by reducing production risks.

Although forage sorghum is not commonly grown in the northeastern United States, it could be a competitive alternative to corn silage in the region due to its water use efficiency and drought tolerance (Martin, 1930; Martin et al., 1976; Howell et al., 1997; Lamm et al., 2007; Merrill et al., 2007). Forage sorghum requires higher soil temperatures for planting (16°C minimum), with optimum soil temperatures for germination ranging from 21 to 35°C (Peacock and Heinrich, 1984). Typically, this range in soil temperatures does not occur until early June in the Northeast. Thus, forage sorghum could be planted instead of corn for silage if timely planting of corn is not successful or not possible due to weather. Another useful option for forage sorghum is in double-cropped forage rotations, where a later planting allows for harvest of the winter cereal forage crop in mid- to late-May (Goff et al., 2010; Lyons et al., 2018).

Some forage sorghum varieties have similar yields to corn silage (Marsalis et al., 2010). However, the more digestible brachytic dwarf brown midrib (BMR) varieties have typically been associated with lower yields (Oliver et al., 2005; Marsalis et al., 2009; Marsalis et al., 2010). For example, Marsalis et al. (2010) found that corn silage and a conventional forage sorghum cultivar yielded the same (24.4 Mg DM ha^{-1}), whereas a BMR forage sorghum cultivar yielded about 13% less than the conventional varieties (21.1 Mg DM ha^{-1}). Improved varieties of BMR forage sorghum can yield more than older varieties (Oliver et al., 2005), such as those with the brachytic dwarf trait, which have shortened internodes that can result in higher yield due to maintained leaf production and tillering. Brachytic dwarf varieties are also less prone to lodging due to their shortened stature (Pendleton and Seif, 1961).

Corn silage is commonly fed to lactating dairy cows due to the high amount of energy it supplies for maximum milk production. Although certain forage sorghum varieties have a nutritive value comparable to corn silage (Grant et al., 1995; Aydin et al., 1999; Oliver et al., 2004; Marsalis et al., 2010), starch concentrations are often lower in forage sorghum than in corn silage (Oliver et al., 2004). Conventional forage sorghum is also generally less digestible than corn silage, but BMR varieties have increased sorghum silage quality due to reduced lignin concentrations and improved fiber digestibility (Grant et al., 1995; Oliver et al., 2004). Additionally, brachytic dwarf sorghum varieties can help improve digestibility due to increased leaf-to-stem ratios (Pendleton and Seif, 1961). Thus, with improved sorghum varieties and proper ration balancing, forage sorghum can be a valuable alternative to corn silage for dairy rations in the Northeast, particularly during years with adverse weather conditions.

Nitrogen recommendations for forage sorghum have been determined in the West and Midwest for both dryland and irrigated forage sorghum production (Leikam et al., 2003; Westfall and Davis, 2005; Marsalis et al., 2010; Maughan et al., 2012; Haankuku et al., 2014; Oklahoma Cooperative Extension, 2017). Fertilizer N recommendations in Kansas for forage sorghum are based on yield goals and soil organic matter (SOM) concentration and adjusted based on previous crop, manure, other N additions to the soil, or based on actual soil nitrate measurements. Recommended N rates in Kansas range from 0 kg N ha^{-1} (40 g kg^{-1} SOM, 22.4 Mg ha^{-1} yield goal) to 336 kg N ha^{-1} (10 g kg^{-1} SOM, 67 Mg ha^{-1} yield goal, irrigated) (Leikam et al., 2003). Colorado recommendations are determined using SOM concentration as well as soil NO_3-N, and adjusted for manure or legume histories (Westfall and Davis, 2005). Baseline recommendations (no legume or manure adjustments; irrigated) range from 7 kg N ha^{-1} (> 20 g kg^{-1} SOM, > 12 mg kg^{-1} NO_3-N) to 258 kg N ha^{-1} (0 to 10 g kg^{-1} SOM, 0 to 3 mg kg^{-1} NO_3-N). In contrast, recommendations for N in Oklahoma are solely based on yield goals regardless of irrigation, SOM, or previous N additions. In Oklahoma, possible yield goals for sorghum silage range from 11 to 67 Mg ha^{-1} with corresponding N recommendations of 50 to 336 kg N ha^{-1}, or an average of 5 kg N per Mg yield (Oklahoma Cooperative

Extension, 2017). Although some forage sorghum varieties require less N than corn silage (Marsalis et al., 2010) and NUE for sorghum can be less than corn silage at the same N rates (Muchow, 1998), N recommendations for forage sorghum in Kansas, Colorado, and Oklahoma are the same as for corn silage (Leikam et al., 2003; Westfall and Davis, 2005; Oklahoma Cooperative Extension, 2017).

Nitrogen recommendation systems for sorghum should be crop-specific and reflect new varieties of forage sorghum and different growing conditions. To date, no recommendation systems have been developed for BMR forage sorghum in the northeastern United States. The purpose of this study is to determine the MERN and the yield and quality at the MERN for a brachytic dwarf BMR forage sorghum cultivar in New York based on data from 13 trials conducted over five years.

MATERIALS AND METHODS

Locations and Experimental Design

Thirteen BMR forage sorghum N-rate trials were established from 2013 to 2017. Four trials each were conducted at the Pullyen-Tailby Research Farm in Tompkins county, NY, in 2013 (trial 1), 2014 (trial 3), 2015 (trial 5), and 2017 (trial 11), and at the Musgrave Research Farm in Cayuga county, NY, in 2014 (trial 2), 2015 (trial 4), 2016 (trial 7), and 2017 (trial 10). Two trials were conducted at the Willsboro Research Farm in Essex county, NY, in 2017 (A, trial 12, and B, trial 13). Because these trials were on research farms, previous crops do not necessarily reflect common forage crop rotations or manure application regimes in the region (Table 5.1).

Table 5.1. Location, soil type, soil management group (SMG), and planting and harvest information for 13 brachytic dwarf brown midrib forage sorghum trials in New York from 2013 to 2017.

Trial	County	Soil type	Soil description	SMG	Planting date	Harvest date	Previous crop	Row spacing (cm)
1, 3, 5, 11	Tompkins	Hudson and Collamer silt loams	Fine, illitic, mesic Glossaquic Hapludalfs; Fine-silty, mixed, semiactive, mesic Glossaquic Hapludalfs	3	6/4/13 6/21/14 6/12/15 6/9/17	9/23/13 10/13/14 10/14/15 10/2/17	Tomatoes (2012)	38
2, 4, 7, 10	Cayuga	Lima silt loam	Fine-loamy, mixed, semiactive, mesic Oxyaquic Hapludalfs	2	6/20/14 6/2/15 6/3/16 6/12/17	10/13/14 10/21/15 9/20/16 10/5/17	Corn (2013)	38
6	Jefferson	Rhinebeck silt loam	Fine, illitic, mesic Aeric Endoaqualfs	2	6/4/16	10/7/16	Grass/ clover	76
8	St. Lawrence A	Hogansburg loam	Coarse-loamy, mixed, semiactive, frigid Aquic Eutrudepts	4	6/2/16	9/30/16	Corn	19
9	St. Lawrence B	Stockholm loamy fine sand	Sandy over clayey, mixed, superactive, frigid Umbric Epiaquods	5	6/10/16	9/27/16	Corn	38
12	Essex A	Kingsbury silty clay loam	Very-fine, mixed, active, mesic Aeric Endoaqualfs	1	6/15/17	10/4/17	Corn	38
13	Essex B	Stafford fine sandy loam	Mixed, mesic Typic Psammaquents	4	6/15/17	10/4/17	Grass sod	38

Three trials were established on commercial farms: one in Jefferson county, NY (trial 6) and two in St. Lawrence county, NY (A, trial 8, and B, trial 9). Trial 6 followed a grass/legume stand, trial 8 had a recent manure history (within the last year), and trial 9 followed corn (Table 5.1). Field information obtained for each trial includes soil type, previous crop, and planting and harvest dates (Table 5.1).

Weather data were collected from the Cornell University weather station in Tompkins county, approximately 5 km from the Tompkins county trials, on-site weather stations for the Cayuga county and Essex county trials, the Watertown weather station, approximately 40 km from the Jefferson county trial, and the Canton 4 SE station, approximately 25 km from the St. Lawrence county trials (NRCC, 2016). Precipitation was approximately normal for the 2013 and 2014 growing seasons. In 2015 and 2017, there was more precipitation in the spring and early summer compared to normal, and 2016 had a very dry spring and early summer (Table 5.2).

Table 5.2. Monthly precipitation and temperatures for 13 sites in New York where brachytic dwarf BMR forage sorghum trials were conducted from 2013 to 2017. Data were obtained from within-county weather stations (NRCC, 2016). The average monthly temperatures were determined from calculated daily averages [(maximum daily temperature – minimum daily temperature)/2]. Values in parenthesis represent differences from the 30 year average.

Trial		June		July		August		September		October		Total
Total monthly precipitation		----------	----------	----------	----------	cm	----------	----------	----------	----------	----------	
1	2013	10.5	(+ 0.7)	17.7	(+ 8.7)	13.3	(+ 4.7)	9.6	(- 0.2)	6.8	(- 1.4)	58
2	2014	7.3	(- 3.1)	11.7	(+ 3.3)	11.3	(+ 2.1)	5.9	(- 4.8)	6.5	(- 1.6)	43
3	2014	13.1	(+ 3.3)	9.8	(+ 0.8)	15.4	(+ 6.8)	5.6	(- 4.2)	7.6	(- 0.6)	52
4	2015	20.3	(+ 9.9)	7.1	(- 1.3)	3.5	(- 5.7)	13.2	(+ 2.5)	7.2	(- 0.9)	51
5	2015	16.7	(+ 6.9)	12.5	(+ 3.5)	3.6	(- 5.0)	10.1	(+ 0.3)	5.6	(- 2.6)	49
6	2016	7.9	(- 0.7)	1.5	(- 6.9)	12.9	(+ 2.9)	7.0	(- 4.7)	19.1	(+ 9.5)	48
7	2016	2.8†	(- 7.6)	4.8†	(- 3.6)	11.6†	(+ 2.4)	9.6†	(- 1.1)	20.5	(+ 12.4)	49
8, 9	2016	9.6	(+ 1.3)	7.6	(- 1.5)	6.4	(- 3.9)	5.6	(- 5.2)	17.9	(+ 9.4)	47
10	2017	9.7	(- 0.7)	18.6	(+ 10.2)	3.8	(- 5.4)	6.6	(- 4.1)	15.2	(+ 7.1)	54
11	2017	9.4	(- 0.4)	16.9	(+ 7.9)	6.0	(- 2.6)	5.6	(- 4.2)	17.9	(+ 9.7)	56
12, 13	2017	18.5	na‡	5.7	na‡	6.1	na‡	4.9	na‡	8.6	na‡	44

Table 5.2 (Continued)

Trial		June		July		August		September		October		Total
Average monthly temperature -- °C --												
1	2013	18.0	(+ 0.0)	21.8	(+ 1.4)	18.7	(- 0.9)	14.3	(- 0.9)	10.8	(+ 1.7)	
2	2014	19.1	(- 0.2)	20.3	(- 1.5)	19.0	(- 1.9)	16.1	(- 0.6)	11.6	(+ 1.1)	
3	2014	18.4	(+ 0.4)	19.9	(- 0.5)	18.0	(- 1.6)	15.4	(+ 0.2)	10.8	(+ 1.7)	
4	2015	17.8	(- 1.5)	20.4	(- 1.4)	19.8	(- 1.1)	19.2	(+ 2.5)	9.9	(- 0.6)	
5	2015	17.6	(- 0.4)	19.6	(- 0.8)	19.4	(- 0.2)	18.4	(+ 3.2)	9.0	(- 0.1)	
6	2016	18.7	(+ 0.2)	22.6	(+ 1.4)	23.3	(+ 3.0)	18.1	(+ 2.5)	10.8	(+ 1.8)	
7	2016	18.6	(- 0.7)	22.1	(+ 0.3)	22.8	(+ 1.9)	18.2	(+ 1.5)	11.5	(+ 1.0)	
8, 9	2016	18.2	(+ 0.5)	21.6	(+ 1.2)	22.2	(+ 3.1)	16.9	(+ 2.6)	10.3	(+ 2.5)	
10	2017	18.7	(- 0.6)	20.8	(- 1.0)	19.5	(- 1.4)	17.3	(+ 0.6)	13.8	(+ 3.3)	
11	2017	17.9	(- 0.1)	20.3	(- 0.1)	18.6	(- 1.0)	16.2	(+ 1.0)	12.6	(+ 3.5)	
12, 13	2017	18.3	na‡	20.0	na‡	19.1	na‡	17.3	na‡	13.6	na‡	

† 2-7 days of missing weather records.
‡ na, not applicable.

All trials were organized in a randomized complete block design with four replications and five rates of fertilizer N broadcasted (surface-applied) at planting (0, 56, 112, 168, and 224 kg N ha^{-1}) as Agrotain ultra-treated urea (Koch Agronomic Services, LLC, Wichita, KS). All trials underwent primary and secondary tillage prior to planting and fertilization. In 2015, 2016, and 2017, the Cayuga county trials had two additional rates of N (280 and 336 kg N ha^{-1}) due to a lack of a yield plateau in 2014. Prior to fertilization, soil was sampled (0- to 20- cm depth) in each plot and composited by replication for baseline soil fertility (Table 5.3).

Table 5.3. Baseline soil fertility status for 13 sites in New York where brachytic dwarf brown midrib forage sorghum trials were conducted from 2013 to 2017. Values are averages of four 0- to 20-cm core soil samples within each field.

Grp†	Trial	County	Year	pH	SOM‡	Morgan-NO_3-N§	Morgan-P§	Morgan-K§
					g kg^{-1}	---------------- mg kg^{-1}		-----------------
1	6	Jefferson	2016	6.6	48	32.3	22.0 (VH)	272 (VH)
	8	St. Lawrence A	2016	7.4	34	30.6	12.5 (H)	134 (VH)
			Average	7.0	41	31.5	17.3	203
2	2	Cayuga	2014	7.7	22	8.4	5.2 (H)	59 (H)
	5	Tompkins	2015	5.6	20	7.9	17.0 (H)	150 (VH)
	12	Essex A	2017	6.8	45	6.0	2.2 (M)	56 (H)
	13	Essex B	2017	6.7	19	3.8	8.0 (H)	38 (L)
			Average	6.7	27	6.5	8.1	76
3	1	Tompkins	2013	6.1	22	0.03	25.0 (VH)	188 (VH)
	3	Tompkins	2014	5.9	27	3.2	18.7 (H)	288 (VH)
	4	Cayuga	2015	7.5	24	3.7	7.1 (H)	58 (H)
	7	Cayuga	2016	8.0	24	7.9	5.3 (H)	51 (H)
	9	St. Lawrence B	2016	5.5	09	3.5	4.0 (M)	85 (H)
	10	Cayuga	2017	7.9	23	4.8	5.3 (H)	70 (H)
	11	Tompkins	2017	6.1	25	1.6	19.2 (H)	162 (VH)
			Average	6.7	25	7.1	13.3	147

†Trials were categorized into three groups based on yield response to N: (1) no response to N (MERN = 0; two trials), (2) no yield plateau (MERN > 224 kg N ha^{-1}; four trials), and (3) a yield plateau between the lowest and highest N rates (seven trials).
‡Soil organic matter (SOM) determined by loss on ignition (Storer, 1984).
§Morgan extraction (Morgan, 1941). L, low; M, medium; H, high; VH, very high, and N, normal according to Cornell Cooperative Extension (2016).

Planting and Harvest

A brachytic dwarf BMR forage sorghum cultivar (AF7102, Alta Seeds, Irving, TX) adapted to the northeastern United States was used for all trials. With the exception of trials 6 and 8, all trials were drilled at a planting depth of approximately 3 cm using 17 kg seed ha^{-1} with 38-cm row spacing. Trial 6 was planted with 76-cm row spacing, and trial 8 had 19-cm row spacing. Plot sizes were 9 × 3 m in 2013, 2016, and 2017, and 18 × 3 m in 2014 and 2015. Pre-emergence herbicide was applied soon after planting (1.12 kg ha^{-1} atrazine and 1.42 kg ha^{-1} S-Metolachlor). Sorghum was harvested at the soft dough stage (stage 7) according to Vanderlip and Reeves (1972), at a 10-cm cutting height in a 1.5 m × 4 row area per plot. To avoid differences in measured yield due to stand irregularity, gaps between individual plants greater than approximately 30 cm were recorded and deducted from the harvest area. Plants were coarsely ground using a leaf shredder-chipper (MacKissic Inc., Parker Ford, PA), subsampled, placed in sealed plastic bags, and put on ice to be brought back to the laboratory for drying. Forage subsamples were dried in a forced-air oven at approximately 55°C until stable weights were reached and DM concentration was determined.

Soil and Forage Analysis

Dried sorghum biomass was ground to pass a 1-mm screen with a Wiley mill (Thomas Scientific, Swedesboro, NJ) and submitted to Cumberland Valley Analytical (Waynesboro, PA) for analysis (Foss 5000 NIR; Foss, Hilleroed, Denmark). Total forage N was multiplied by 6.25 to determine CP concentration following Method 46-

10.01 of AACC (AACC International, 1999). Forage nutritive value parameters, including neutral detergent fiber (NDF), total digestible nutrients (TDN), and starch were analyzed for all trials except for trials 2 and 3.

Soil composites were oven-dried at 50°C and ground to pass a 2-mm screen. Samples were submitted for baseline fertility analysis to the Analytical Laboratory and Maine Soil Testing Service in Orono, ME, and analyzed for Morgan extracted NO_3-N at the Nutrient Management Spear Program Laboratory in Ithaca, NY. Soil pH was measured in a 1:1 (w/v) water extract, and SOM was determined by loss-on-ignition through exposure to 500°C for two hours (Storer, 1984). The Cornell Morgan soil test was used to extract P, K, Mg, Ca, Mn, and Zn by shaking dried samples in a 1:5 (v/v) ratio for 15 min in Morgan solution (1 M sodium acetate buffered at pH 4.8; Morgan, 1941). The extracts were filtered through a Whatman No. 2 equivalent filter paper following procedures outlined in NEC-1012 (Northeast Coordinating Committee for Soil Testing, 2011). The filtered extracts were analyzed for K, Mg, Ca, Mn and Zn using an inductively coupled plasma atomic emission spectrometer (ICP-AES, JY70 Type II, Jobin Yvon, Edison, NJ). Phosphorus was determined colorimetrically using the ammonium molybdate-ascorbic acid method (Knudsen and Beegle, 1988) with a Lachat QuikChem® 8000 flow injection analyzer (Lachat Instruments, Milwaukee, WI). The Morgan extraction (Morgan, 1941) was used to determine soil NO_3-N with a discrete analyzer (EasyChem Plus, Chinchilla Scientific, LLC, Oak Brook, IL).

Five trials had soil pH values outside the ideal range of 5.5 to 7.0 for sorghum production (Oklahoma Cooperative Extension, 2017; Table 5.3). However, there was no correlation between soil pH and yield (P = 0.648), and therefore trials that had pH values outside of this range were still included in the analyses. Soil organic matter ranged from 9 to 48 g kg^{-1}. Trials 6 and 8 had higher soil NO_3-N at planting (32.3 and 30.6 mg NO_3-N kg^{-1}, respectively, reflecting manure and legume histories) compared to the other trials, which ranged from 0.03 to 8.4 NO_3-N mg kg^{-1}. Soil test P was medium for two trials, high for nine trials, and very high for two trials according to soil fertility interpretations of Cornell University (Cornell Cooperative Extension, 2016). Soil test K was either high or very high for all trials except for trial 13 which was classified as low in soil test K. According to forage analysis, forage K concentrations for trial 13 (ranging from 12.5 to 18.6 g kg^{-1} DM), and forage P concentrations for trials 9 and 12 (ranging from 1.0 to 1.7 g kg^{-1} DM) were within the range of forage P and K concentrations of trials with adequate soil test P and K, so all 13 trials were included in the analyses.

Statistical Analysis

Due to variations in yield responses across years at the same locations, trials were analyzed individually using PROC MIXED of SAS v. 9.4 with the Tukey adjustment for multiple comparisons (SAS Institute, 1999). Nitrogen rate was considered a fixed effect and replication as a random effect. Mean differences were considered significant at $P \leq 0.05$. The MERN was determined for each trial using a quadratic plateau model (PROC NLIN) (SAS Institute, 1999):

$$Yield\ plateau\ (kg\ N\ ha^{-1}) = \frac{-b}{2c} \qquad [5.1]$$

and the MERN:

$$MERN\ (kg\ N\ ha^{-1}) = \frac{N\ cost - b \times crop\ value}{2c \times crop\ value} \qquad [5.2]$$

where *b* is the linear coefficient, *c* is the quadratic coefficient, N cost is \$1.54 kg^{-1}, and crop value is \$108.86 Mg^{-1} DM. Other crop values and N costs can be used for future MERN calculations based on fitting parameters of the quadratic plateau models for N responsive sites.

Two measures of efficiency, NUE and ANR, were calculated for each trial in group 3. The NUE is the increase in DM yield beyond the control per kg N applied (Eq. 5.3); ANR is the additional N removed beyond the control in harvested forage per kg N applied (Eq. 5.4) (Ketterings et al., 2007):

$$NUE\ (kg\ DM\ yield\ kg^{-1}N) = \frac{DM\ yield\ of\ N_{rate} - DM\ yield\ of\ control\ (kg\ DM\ ha^{-1})}{N\ applied\ (kg\ N\ ha^{-1})} \qquad [5.3]$$

$$ANR\ (\%) = \frac{Forage\ N\ of\ N_{rate}\ (kg\ N\ ha^{-1}) - Forage\ N\ of\ control\ (kg\ N\ ha^{-1})}{N\ applied\ (kg\ N\ ha^{-1})} \qquad [5.4]$$

RESULTS AND DISCUSSION

Yield and the Most Economic Rate of N

Yield responses to N in the 13 trials fell into three groups: group 1, no response to N (MERN = 0 kg N ha^{-1}; two trials), group 2, no yield plateau (MERN > 224 kg N ha^{-1}; four trials), and group 3, a yield plateau between the lowest and highest N rates (seven trials) (Tables 5.4 and 5.5). The MERNs for the seven trials included in the third group ranged from 150 to 262 kg N ha^{-1} (average 203 kg N ha^{-1}).

Table 5.4. Quadratic plateau model parameter estimates for determining the most economic rate of N (MERN) for seven brachytic dwarf brown midrib forage sorghum trials in New York from 2013 to 2017. See Tables 1 and 3 for a description of the sites.

Trial	County	Year	Model *P*	a	b	c	Yield plateau	MERN
							--- kg N ha^{-1} ---	
1	Tompkins	2013	0.0001	4.71813	0.05603	-0.00013657	230	206
3	Tompkins	2014	< 0.0001	3.00049	0.04643	-0.00014489	180	157
4	Cayuga	2015	0.0001	3.48672	0.05314	-0.00011002	271	241
7	Cayuga	2016	0.0530	5.75017	0.01408	-0.00002015	392	229
9	St. Lawrence B	2016	0.0034	6.14666	0.04112	-0.00011172	206	177
10	Cayuga	2017	< 0.0001	4.50470	0.02651	-0.00004411	337	262
11	Tompkins	2017	< 0.0001	3.52040	0.08034	-0.00027720	162	150

Table 5.5. The most economic rate of nitrogen (N) (MERN) and dry matter (DM) yield, forage N uptake, N use efficiency (NUE), and apparent N recovery (ANR) at the MERN for 13 brachytic dwarf brown midrib forage sorghum trials in New York from 2013 to 2017. See Tables 1 and 3 for a description of the sites.

					------------ at the MERN -----------			
Group†	Trial	County	Year	MERN	DM yield	N uptake	NUE	ANR
				kg N ha^{-1}	Mg DM ha^{-1}	kg ha^{-1}	kg DM kg^{-1} N	%
1	6	Jefferson	2016	0	11.9‡	191§	na¶	na¶
	8	St. Lawrence A	2016	0	25.5‡	347§	na¶	na¶
			Average	0	20.7	269	na¶	na¶
2	2	Cayuga	2014	> 224	17.9#	210#	na¶	na¶
	5	Tompkins	2015	> 224	15.9#	227#	na¶	na¶
	12	Essex A	2017	> 224	15.2#	170#	na¶	na¶
	13	Essex B	2017	> 224	21.5#	289#	na¶	na¶
			Average	> 224	17.6	224	na¶	na¶
3	1	Tompkins	2013	206	23.3	302	86‡	110‡
	3	Tompkins	2014	157	15.0	167	57	64‡
	4	Cayuga	2015	241	22.0	298	60‡	85‡
	7	Cayuga	2016	229	17.5	263	21	56
	9	St. Lawrence B	2016	177	22.2	316	40‡	87‡
	10	Cayuga	2017	262	18.6	223	34‡	45‡
	11	Tompkins	2017	150	20.8	268	97	135
			Average	203	19.9	262	56	83

†Trials were categorized into three groups based on yield response to N: (1) no response to N (MERN = 0; two trials), (2) no yield plateau (MERN > 224 kg N ha^{-1}; four trials), and (3) a yield plateau between the lowest and highest N rates (seven trials).

‡There were no differences among treatments, so the average value across all N rates is reported.

§Values are the average of the 0 kg N rate.

¶na, not applicable.

#A yield plateau was not reached, therefore no MERN could be determined. The average value of the highest N rate is reported.

The two trials with MERNs of 0 (trials 6 and 8) had higher soil nitrate concentrations at planting than the other trials (32.3 and 30.6 mg kg^{-1} for trials 6 and 8, respectively, vs 4.6 mg kg^{-1} average for trials with positive MERNs; Table 5.3) and relatively high SOM (48 and 34 g kg^{-1} for trials 6 and 8, respectively, vs. 24 g kg^{-1} average for trials with positive MERNs). Trial 8 had a recent manure history, and trial 6 was previously a grass/clover stand, both of which could have provided sufficient soil nitrate to result in a lack of sorghum yield response to N fertilizer. These results are consistent with those of other studies showing that residual N in the soil after manure applications or legume stands reduces the N needs of subsequent crops (Hesterman et al., 1984; Bruulsema and Christie, 1986; Ketterings et al., 2007; Morris et al., 2013). Yields at the MERN were 11.9 and 25.5 Mg DM ha^{-1} for trials 6 and 8, respectively (Figure 5.1a; Table 5.5). Trial 8 was the highest yielding of all trials; trial 6 was the lowest yielding. Trial 6 had a wider row spacing than recommended during a drought year, which resulted in weed pressure that could have impacted performance. Similarly, Miron et al. (2007) in Israel measured low BMR forage sorghum yields (10.8 Mg DM ha^{-1}) with large row spacing, but no information on stand vigor or weed population was given in that study. In contrast, the narrow row spacing in trial 8 resulted in full suppression of weeds.

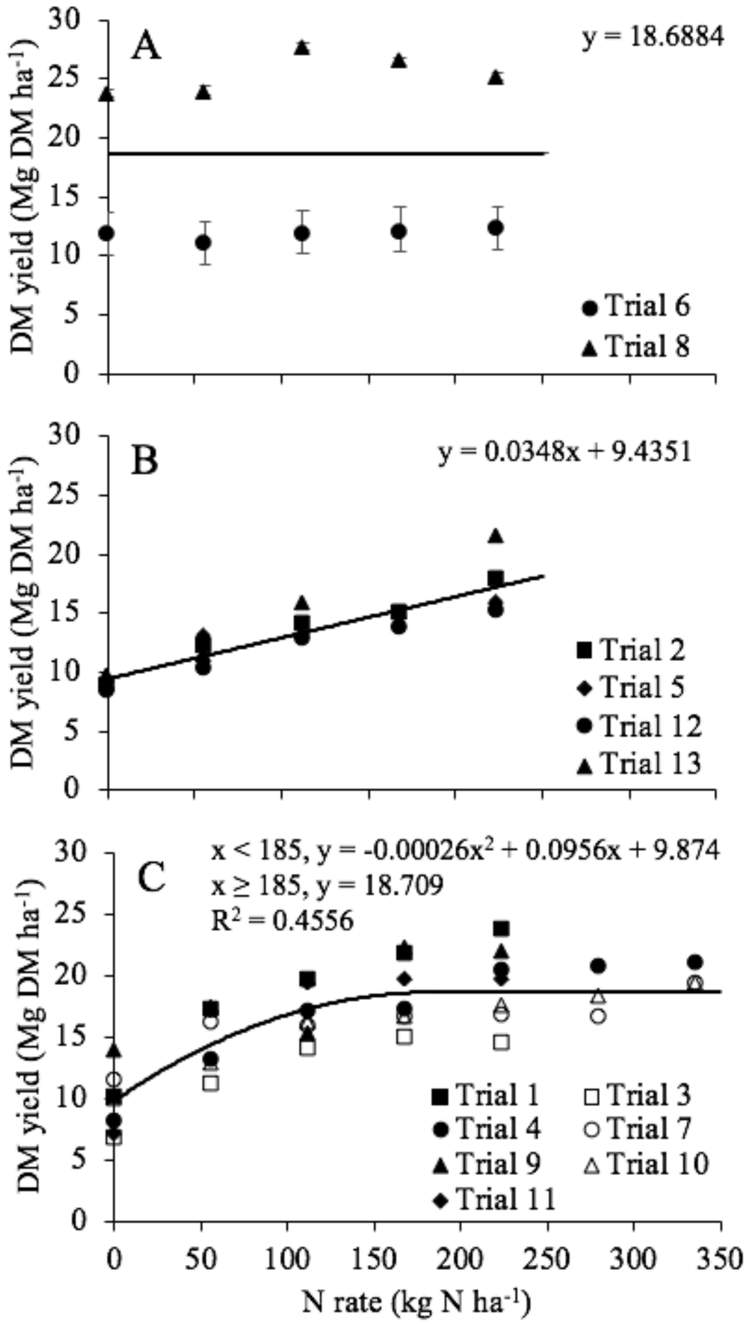

Figure 5.1. Impact of N application on dry matter (DM) yield of brachytic dwarf brown midrib sorghum for 13 trials in New York from 2013 to 2017. Two trials did not respond to N addition (A), four trials lacked a yield plateau (B), and seven trials had a yield plateau between the lowest and highest N rates (C). Error bars in A represent SEM. See Tables 1 and 3 for a description of the sites.

The four trials with no yield plateau (MERNs exceeded the highest rate of N applied) included trials 2, 5, 12, and 13 (Figure 5.1b). Trial 2 was a very N-responsive site, as were all subsequent Cayuga county trials (trials 4, 7, and 10), with MERNs > 224 kg N ha^{-1}. Regardless of N needs, the maximum yield obtained for trial 2 (17.9 Mg DM ha^{-1}) was similar to trials at the same location in subsequent years (22.0, 17.5, and 18.6 Mg DM ha^{-1} for trials 4, 7, and 10, respectively). Trial 5 required more N to reach a plateau than other years at the Tompkins county location but yielded similar to trial 3 (15.0 and 15.9 Mg DM ha^{-1} for trials 3 and 5, respectively), which required 157 kg N ha^{-1}. Trial 5 experienced more rain in June than other trials at this location, which could have caused some fertilizer N loss following planting. However, trial 5 had higher nitrate at planting (7.9 mg kg^{-1}) than trials 1, 3, and 11 (1.6 mg kg^{-1} average) which could have supported the similar CP and N uptake of trial 5 as compared to the other Tompkins county trials (Tables 5.5 and 5.6). Further investigation is needed to explain the high N needs that year. Trials 12 and 13, although on the same farm, had very different soil types (silty clay loam for trial 12, and fine sandy loam for trial 13 (Table 5.1). However, neither of these trials had a recent manure or legume history. The trial on clay soil had a maximum yield of 15.2 Mg DM ha^{-1}, whereas on the sandy soil a maximum yield of 21.5 Mg DM ha^{-1} was obtained. Soil drainage likely played a part in the yield responses for these two trials because considerable rainfall occurred in June 2017 after planting (18.5 cm) at this location (Table 5.2). This could have resulted in better early seedling development for the trial on the sandy soil, supporting more vigorous growth. Further investigation at the Essex county location is needed to determine why both trials required more than

224 kg N ha^{-1}.

The seven trials in the third group had MERNs ranging from 150 to 262 kg N ha^{-1} (average, 203 kg N ha^{-1}) while yields at the MERN ranged from 15.0 to 23.3 Mg DM ha^{-1} (average, 19.9 Mg DM ha^{-1}) (Figure 5.1c; Table 5.5). This range in MERNs is slightly higher than the current recommended N rates for corn silage in New York. Current recommended N rates for corn silage in New York range from a starter of 11 to 34 kg N ha^{-1} directly following a plowed sod to 78 to 146 kg N ha^{-1} sidedress N for fourth-year or higher corn on fields without a manure history (Ketterings et al., 2003).

The yield ranges in this study are similar to those of a study with BMR forage sorghum in New Mexico, which yielded 21.1 Mg DM ha^{-1} (Marsalis et al., 2010). Another non-irrigated study in Nebraska had lower BMR forage sorghum yields compared to our study (9.7 and 13.5 Mg DM ha^{-1} for two BMR varieties) but no planting information was given (Oliver et al., 2004). On average, the sorghum in this study required approximately 10 kg N ha^{-1} per Mg DM ha^{-1}. This requirement was higher than that suggested in Oklahoma, which recommends approximately 5 kg N ha^{-1} for every Mg DM ha^{-1} (Oklahoma Cooperative Extension, 2017), further emphasizing the need for region-specific N guidelines.

Except for 2015, in which the MERN was > 224 kg N ha^{-1}, the Tompkins county trials had MERNs between 150 and 200 lbs N ha^{-1}. In 2013 and 2017, trials at this location had higher yields at the MERN (23.3 and 20.8 Mg DM ha^{-1} for trials 1 and 11, respectively) than those in other years (15.0 and 13.0 Mg DM ha^{-1} for trials 3 and 5, respectively). There was more precipitation than normal in July, followed by normal precipitation for the rest of the season for trials 1 and 11. In contrast, there was more precipitation in August for trial 3 and in June and July for trial 5, and less precipitation than normal in August for trial 5. Thus, we propose that rainfall patterns across years could explain some of the yield variation at this location. Cayuga county trials consistently needed between 230 and 260 kg N ha^{-1}, and all years yielded similarly (18 Mg DM ha^{-1}) except for trial 4, which yielded 22 Mg DM ha^{-1}. The two trials with sandy soils (trials 9 and 13) yielded similarly, but trial 13 had a much higher MERN. The difference in precipitation at these two locations may explain the difference in N needs: trial 9 had normal precipitation in June and July but then less precipitation than normal in August and September, whereas trial 13 had more precipitation than normal in June.

Results suggest that yield response and N needs for BMR forage sorghum in the northeastern United States is site- and year-specific. Research on BMR forage sorghum in conditions with relatively high amounts of natural precipitation is lacking because most sorghum research has been conducted in regions where it is grown as a dryland crop or in irrigated systems (Leikam et al., 2003; Westfall and Davis, 2005; Marsalis et al., 2010; Maughan et al., 2012; Haankuku et al., 2014; Oklahoma Cooperative Extension, 2017*)*. Growing BMR forage sorghum in the northeastern United States presents a unique situation, as producers are dependent on weather, contributing to more variable results in yield.

Across all trials, there was a negative relationship between soil nitrate at planting and MERN ($P = 0.0041$; adjusted $R^2 = 0.5016$); the higher the soil nitrate at planting, the lower the MERN. However, the two trials with higher nitrate levels and MERNs of 0 (trials 6 and 8) had a large influence on this relationship. There were no significant relationships between MERN or yield at the MERN and SOM, planting date, or soil management groups.

Nitrogen Uptake, Nitrogen Use Efficiency, and Apparent Nitrogen Recovery

Nitrogen removal at the MERN ranged from 167 to 347 kg N ha^{-1} (average, 252 kg N ha^{-1}). Nitrogen uptake was driven by yield with a positive linear relationship between N uptake and yield ($P < 0.0001$; $R^2 = 0.85$). Across all trials, N uptake rates were 113 to 254 kg N ha^{-1} on average for the 0 and 224 kg N ha^{-1} treatments, respectively. Nitrogen uptake ranged from 10.0 to 16.8 kg N Mg^{-1} DM (average, 12.3 kg N Mg^{-1} DM). Similar N uptake was reported for BMR forage sorghum by Marsalis et al. (2010), who found an N uptake of approximately 243 kg N ha^{-1} for BMR forage sorghum, yielding 21.1 Mg DM ha^{-1}, or approximately 11.5 kg N per Mg DM yield (calculated based on 72 g kg^{-1} CP). In a study with a short-season grain sorghum, above ground plant N concentration was between 45 and 132 kg ha^{-1} for N rates ranging from 0 to 120 kg N ha^{-1} (Baker and Blamey, 1985), with approximately 29 kg N ha^{-1} taken up per Mg DM ha^{-1} of grain. The differences in N uptake between the current study and Baker and Blamey (1985) are likely due to a silage vs. grain comparison. In our study, two of the trials had no difference in N uptake among N rates ($P > 0.05$; trials 6 and 8). Both of these trials had a MERN of 0 and high soil nitrate at planting, indicating that the sorghum had adequate soil N prior to fertilization, consistent with manure and rotation histories at these locations.

In our study, there was no relationship between NUE and N rate across non-responsive trials (trials 6 and 8; Figure 5.2a) or trials that did not have a MERN (trials 2, 5, 12, and 13; Figure 5.2b). Although only four of the trials had significant differences in NUE among N rates (Trials 1, 5, 7, and 11), there was a negative logarithmic relationship between N rate and NUE across all trials in group 3 (R^2 = 0.3964) (Figure 5.2c). Nitrogen use efficiency averaged 6.6 kg DM kg^{-1} N for the two trials with MERNs of 0 and ranged from 78 to 42 kg DM kg^{-1} N for the 56 and 224 kg N ha^{-1} treatments, respectively, within N-responsive trials. The two additional N rates for trials 4, 7, and 10 resulted in NUE values averaging 31 and 30 kg DM ha^{-1} for the 280 and 336 kg N ha^{-1} treatments, respectively. In our study, the trials that did not respond to N also tended to have lower NUE at the MERN (Table 5.5). Non-responsive trials had NUE at the MERN ranging from -2 to 15 kg DM kg^{-1} N (average, 7 kg DM kg^{-1} N), whereas N-responsive trials had NUE at the MERN ranging from 21 to 97 kg DM kg^{-1} N (average, 50 kg DM kg^{-1} N).

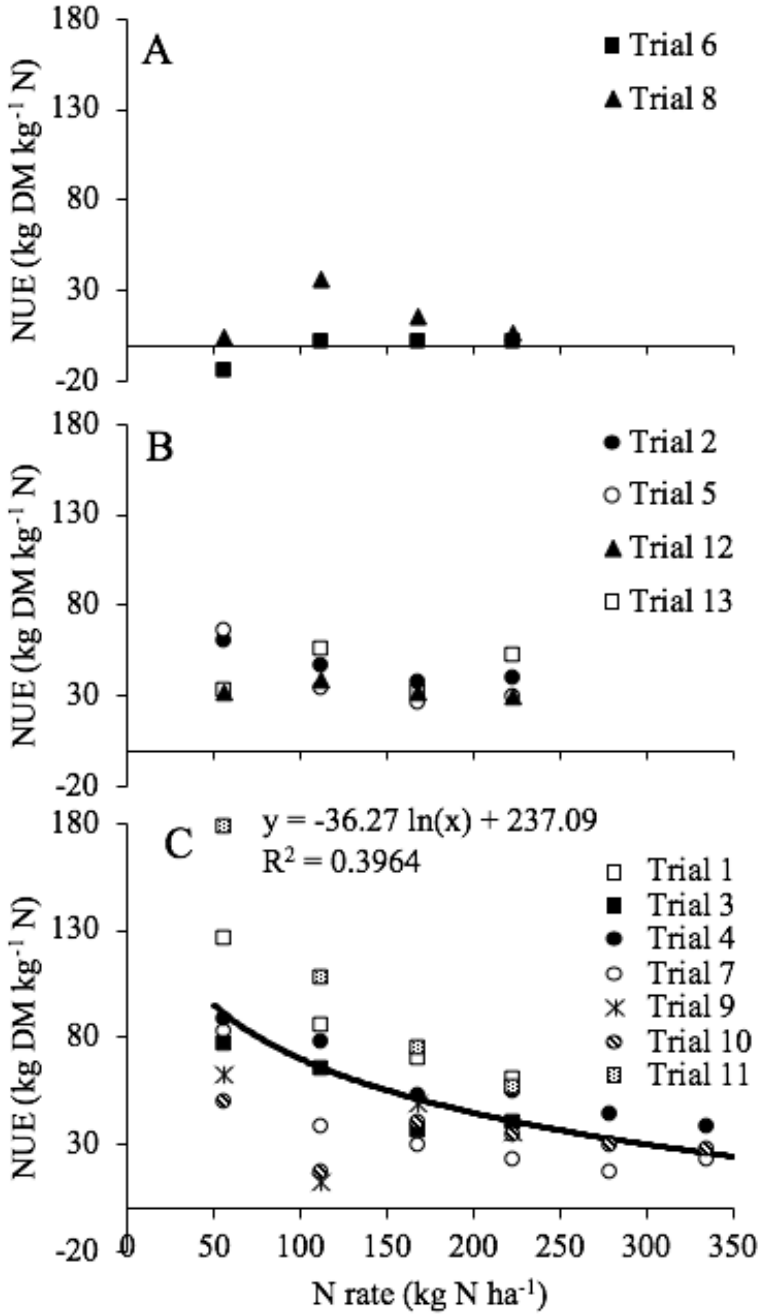

Figure 5.2. Nitrogen use efficiency (NUE) as affected by N application rate for 13 brachytic dwarf brown midrib forage sorghum trials in New York from 2013 to 2017. Two trials did not respond to N (A), four trials had a most economic rate of N (MERN) greater than the highest N rate (B), and seven trials had a MERN between the highest and lowest N rates (C). See Tables 1 and 3 for a description of the sites.

As with NUE, there was no relationship between ANR and N rate across non-responsive trials (trials 6 and 8; Figure 5.3a) or trials that did not have a MERN (trials 2, 5, 12, and 13; Figure 5.3b). Only two trials had differences in ANR among N rates (trials 7 and 11), and, although there was no relationship between ANR and N rate for the N-responsive trials ($P = 0.3139$), ANR tended to decrease with increasing N rates for trials in group 3 (Figure 5.3c). For the non-responsive trials, ANR averaged 21%, while for N-responsive trials ANR averaged 81 and 71% for the 56 and 224 kg N ha^{-1} treatments, respectively. Trials 4, 7, and 10 had ANR values for the 280 and 336 kg N ha^{-1} treatments of 60 and 59%, respectively. Like NUE, ANR at the MERN for trials that did not respond to N were lower than those that did (Table 5.5). Non-responsive trials had ANR at the MERN ranging from 6 to 37% (average, 22%), whereas for N-responsive trials the ANR at the MERN ranged from 33 to 135% (average, 71%). To our knowledge, no other literature on ANR or NUE for BMR forage sorghum is available for comparison.

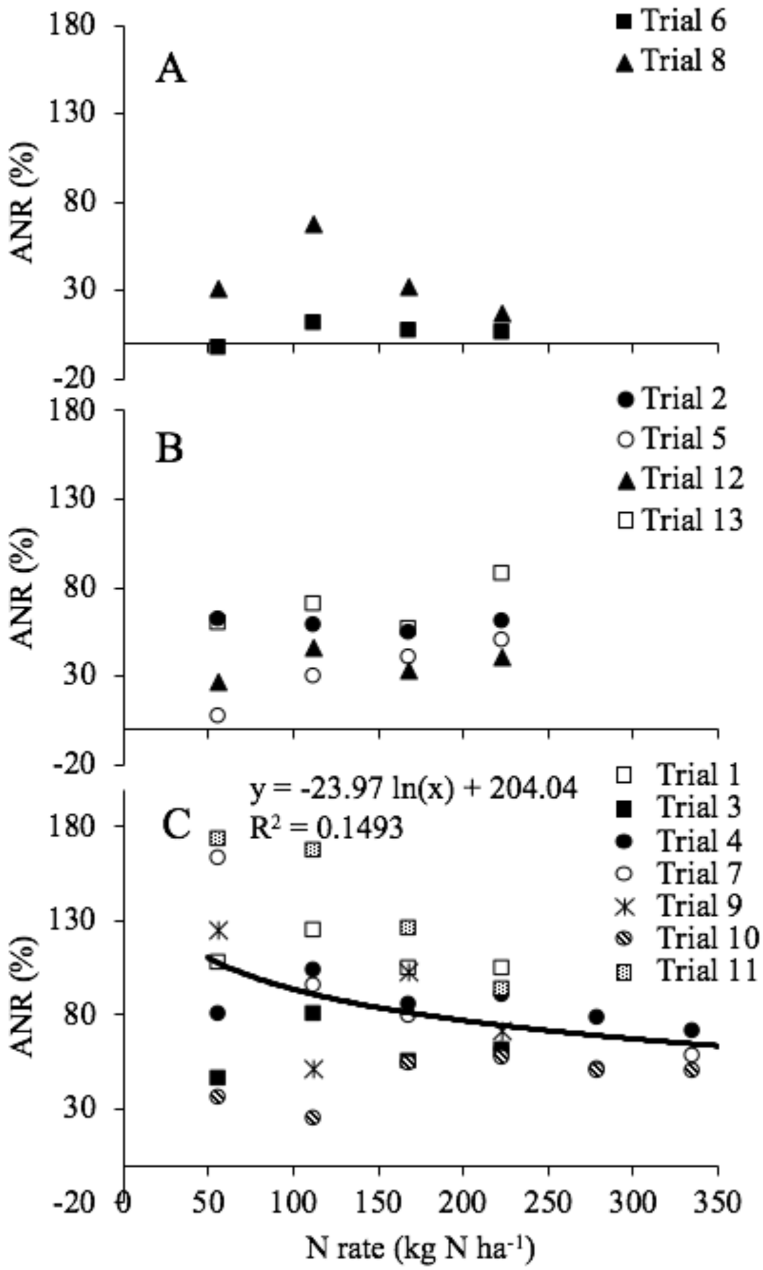

Figure 5.3. Apparent N recovery (ANR) as affected by N application rate for 13 brachytic dwarf brown midrib forage sorghum trials in New York from 2013 to 2017. Two trials did not respond to N (A), four trials had a most economic rate of N (MERN) greater than the highest N rate (B), and seven trials had a MERN between the highest and lowest N rates (C). See Tables 1 and 3 for a description of the sites.

Forage Nutritive Value

The impact of N rate on forage nutritive value was variable among trials. Dry matter concentration was only affected by N rate for trials 1, 2, 3, 10, and 13 (Table 5.6). Dry matter at the MERN ranged from 237 to 322 g kg^{-1} (average, 279 g kg^{-1}). Other studies show similar DM values for BMR sorghum harvested at the late dough stage, which range from 210 to 340 g kg^{-1} (Grant et al., 1995; Aydin et al., 1999; Oliver et al., 2004; Di Marco et al., 2009). Aydin et al. (1999) and Oliver et al. (2004) compared the DM of BMR sorghum with conventional sorghum and corn silage harvested at similar stages of maturity and found that BMR sorghum had higher DM (312 to 335 g DM kg^{-1}) than conventional sorghum (306 g DM kg^{-1}) but lower DM than corn silage (344 to 397 g DM kg^{-1}). Because BMR sorghum silage tends to have greater moisture content at harvest than corn silage, management practices such as using inoculants or wilting post-harvest may be required for proper fermentation. Research on these practices for forage sorghum in the Northeast is needed.

Table 5.6. Dry matter (DM), neutral detergent fiber (NDF), total digestible nutrients (TDN), and starch at the most economic rate of N (MERN) for 13 brachytic dwarf brown midrib forage sorghum trials in New York from 2013 to 2017.

Grp†	Trial	County	Year	MERN	DM	NDF	TDN	Starch	CP
					--------------- at the MERN ---------------				
				kg N ha^{-1}	g kg^{-1}	------------ g kg^{-1} DM ----------			
1	6	Jefferson	2016	0	322‡	428‡	704‡	222‡	100§‡
	8	St. Lawrence A	2016	0	266‡	447‡	710‡	220‡	85§
			Average	0	294	438	707	221	93
2	2	Cayuga	2014	> 224	237¶	na#	na#	na#	74¶
	5	Tompkins	2015	> 224	306‡	458¶	708‡	219‡	89¶
	12	Essex A	2017	> 224	265‡	510¶	653‡	99‡	70‡
	13	Essex B	2017	> 224	258¶	530¶	670‡	137¶	84¶
			Average	> 224	267	499	677	152	79
3	1	Tompkins	2013	206	260	530	663	121	81
	3	Tompkins	2014	157	258	na#	na#	na#	70
	4	Cayuga	2015	241	307‡	461	708	175	85
	7	Cayuga	2016	229	302‡	454‡	717	228‡	94
	9	St. Lawrence B	2016	177	261‡	460	706	182	89
	10	Cayuga	2017	262	298	475‡	691‡	190‡	75
	11	Tompkins	2017	150	275‡	477‡	689‡	184‡	80
			Average	203	280	476	696	180	82

† Trials were categorized into three groups based on yield response to N: (1) no response to N (MERN = 0; 19 trials), (2) no yield plateau (MERN > 135 kg N ha^{-1}; one trial), (3) a yield plateau between 0 and the lowest N rate (34 kg N ha^{-1}; seven trials), and (4) a yield plateau between the lowest and highest N rates (35 trials).
‡ There were no differences among treatments, so the average value across all N rates is reported.
§ Values are the average of the 0 kg N rate.
¶ A yield plateau was not reached, therefore no MERN could be determined and the average value of the highest N rate is reported.
# na, not applicable.

Trials 2, 6, 8, and 12 had no differences in CP among N rates. However, trials 2 and 6 tended to increase in CP with higher N rates (*P* = 0.0677 and 0.1020 for trials 2 and 6, respectively). On average, CP ranged from 62 to 85 g kg^{-1} for the 0 and 224 kg N ha^{-1} treatments, respectively, and CP at the MERN ranged from 70 to 100 g kg^{-1} (average, 83 g kg^{-1}) (Table 5.6). The range in CP in this study is comparable to other studies with BMR forage sorghum harvested at the soft dough stage. Marsalis et al. (2010) found the CP of BMR forage sorghum to be 72 g kg^{-1} (green, or not ensiled), which was similar to the CP concentration of corn (74 g kg^{-1}) and conventional forage sorghum (72 g kg^{-1}) in the same study. Miron et al. (2005) had a BMR forage sorghum with 63 g kg^{-1} CP (both green and silage), and a later study (Miron et al., 2006) had the same BMR cultivar with 73 g kg^{-1} CP (silage). Grant et al. (1995), Aydin et al. (1999), and Oliver et al. (2004) reported 79, 97, and 77 g kg^{-1} CP, respectively, for BMR forage sorghum silage, similar to the CP levels in the current study.

In contrast with CP, N rate did not affect fiber, digestibility, or non-fiber carbohydrate concentrations in most trials. Trials 6, 7, 8, 10, and 11 had no differences in NDF among treatments (Table 5.6). Six trials showed decreased NDF with higher N rates and had NDF ranging from 551 to 490 g kg^{-1} on average for the 0 and 224 kg N ha^{-1} treatments, respectively. Across all trials, aNDF at the MERN ranged from 428 to 530 g kg^{-1} (average, 480 g kg^{-1}). These values are similar to those found in other studies, which range from 480 to 600 g kg^{-1} NDF (Grant et al., 1995; Oliver et al., 2004; Miron et al., 2005, 2006; Marsalis et al., 2010).

Trials 6, 8, 10, 11, 12, and 13 had no difference in TDN among treatments. In general, TDN increased with additional N, but for trials with treatment differences, TDN differed by < 33 g kg^{-1} between the 0 and 224 kg N ha^{-1} treatments. Across all trials, TDN at the MERN ranged from 653 to 717 g kg^{-1} (average, 693 g kg^{-1}). Trials 6, 7, 8, 10, 11, and 12 had no differences in starch concentrations among treatments. For trials with treatment differences, starch increased with higher N rates. Essex B 2017 had the greatest increase in starch, from 73 to 137 g kg^{-1} for the 0 and 224 kg N ha^{-1} treatments, respectively. Across all trials, starch ranged from 150 to 186 g kg^{-1} on average for the 0 and 224 kg N ha^{-1} treatments, respectively, and starch at the MERN ranged from 100 to 230 g kg^{-1} (average, 180 g kg^{-1}). These starch values are similar to those reported by Oliver et al. (2004) for two BMR forage sorghum silage genotypes, which were 168 and 145 g kg^{-1} for BMR-6 and BMR-18 genotypes, respectively. Oliver et al. (2004) found that there was less starch in BMR forage sorghum (157 g kg^{-1}) than in corn silage (200 g kg^{-1}), and the diets containing BMR forage sorghum also had less overall starch (193 g kg^{-1}) than the corn silage diets (210 g kg^{-1}). This suggests that, when feeding BMR forage sorghum in a dairy total mixed ration, supplemental energy may be needed to compensate for the lower starch concentration. Overall, N management most affected CP and had less of an influence on other forage nutritive values, including fiber, digestibility, and non-fiber carbohydrates.

CONCLUSIONS

Thirteen BMR brachytic dwarf forage sorghum N response trials in New York fell into three groups: (1) no response to N fertilizer (MERN=0 kg N ha^{-1}), (2) yield plateau beyond the highest rate of N applied (MERN > 224 kg N ha^{-1}), and (3) a yield plateau between the lowest and highest N rates. Our preliminary results show that brachytic dwarf BMR sorghum grown in fields with recent manure or legume histories may not be responsive to N. For brachytic dwarf BMR forage sorghum planted at recommended seeding rates and row spacings in a rotation without manure or other significant N contributions from previous crops or the soil, our study suggests optimum N rates of approximately 200 kg N ha^{-1}, or 10 kg N ha^{-1} per Mg DM yield. For stands with row spacing greater than 38 cm, weed pressure could impact performance. Nitrogen use efficiency and ANR averaged 50 kg DM kg^{-1} N and 71% for N-responsive trials and 7 kg DM kg^{-1} N and 22% for non-responsive trials, respectively. Applying N beyond the MERN will result in reduced N efficiencies. More research is needed to determine the MERN and associated yield and quality for other varieties of forage sorghum grown in the northeast United States, and for sites with recent manure and/or legume histories.

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CHAPTER 6: OPTIMAL HARVEST TIMING FOR BROWN MIDRIB FORAGE SORGHUM YIELD, NUTRITIVE VALUE, AND RATION PERFORMANCE[1]

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ABSTRACT

Forage sorghum (*Sorghum bicolor* (L.) Moench) is a viable alternative to corn silage (*Zea mays* L.) in double cropping rotations with forage winter cereals in New York due to a later planting date and potentially earlier harvest date of forage sorghum than is typical for corn silage. Our objective was to determine whether harvest of brachytic dwarf brown midrib (BMR) forage sorghum can take place before the currently recommended soft dough harvest time while maintaining dry matter (DM) yield, forage nutritive value, and total mixed ration (TMR) performance. Seven trials were conducted on 2 research farms in central New York from 2014 to 2017. Forage sorghum received 1 of 2 fertilizer N rates at planting (112 and 224 kg N ha^{-1}). Stands

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were harvested at boot, flower, milk, and soft dough stages. Forage samples were analyzed for nutritive value and substituted for corn silage in a typical dairy total mixed ration (TMR) at varying amounts using the Cornell Net Carbohydrate and Protein System (CNCPS). Timing of harvest impacted yield and forage nutritive value for each individual trial and across trials, and the effects were independent of N fertilizer application rate. Averaged across trials, yield ranged from 10.7 Mg DM ha^{-1} for the boot stage to 13.5, 15.2, and 15.8 Mg DM ha^{-1} for the flower, milk, and soft dough stages, respectively. For individual trials, yield either remained constant with harvest beyond the flower stage (4 trials), or beyond the milk stage (1 trial), while for 2 trials yield increased up to the soft dough stage. At the later harvest stages, DM, starch, and non-fiber carbohydrates (NFC) were increased while crude protein (CP), neutral detergent fiber (aNDFom), and 30-h NDF digestibility ($NDFD_{30}$) were decreased. Without adjusting for DM intake, substitution of corn silage by forage sorghum harvested at the soft dough stage resulted in stable predicted metabolizable energy (ME) allowable milk, while the reduced starch content of earlier harvested sorghum resulted in less ME allowable milk with greater substitution of corn silage for sorghum. Forage sorghum can be harvested as early as the flower or milk stage without losing DM yield, allowing for timely planting of forage winter cereal in a double cropping rotation. However, energy supplementation in the diet is needed to make up for reduced starch concentrations with harvest of sorghum at flower and milk growth stages.

INTRODUCTION

Efficient home-grown forage production is critical for the long-term sustainability and profitability of the dairy industry in New York (Soberon et al., 2015). The most common forages grown in the northeast United States are corn silage and alfalfa (*Medicago sativa* L.)/grass mixes, which are typically rotated every 3-to-4 years. Double cropping (harvesting 2 crops within a single growing season) of corn silage with winter cereals such as triticale (x *Triticosecale* Wittm.) and cereal rye (*Secale cereale* L.) grown for silage is becoming a popular practice in the region. The increased adoption of this practice reflects both the economic benefits of having an additional source of on-farm produced forage, and environmental benefits, such as reduced risk of soil erosion and improved uptake and recycling of nutrients between corn silage growing seasons (Ketterings et al., 2015).

It is recommended to plant winter cereals by mid-September and harvest at the flag-leaf stage for optimum forage digestibility (Cherney and Marten, 1982). Harvest at the flag-leaf stage typically occurs in mid- to late-May in New York. The growing season for corn silage can overlap with winter cereal planting in the fall and with harvest in the spring. Thus, alternative warm-season main crops that can be planted in late May or after June 1 (after harvest of the winter cereal) and can be harvested by mid-September need to be evaluated.

Forage sorghum is a warm-season annual grass that requires a minimum soil temperature of 16°C for planting (Peacock and Heinrich, 1984), which does not typically occur in New York until early June. Thus, forage sorghum could fit well in a double crop rotation with winter cereals. In addition to requiring a later planting date, forage sorghum is tolerant to adverse growing conditions including drought and high temperatures (Howell et al., 1997; Lamm et al., 2007; Merrill et al., 2007) which could result in higher yields than for corn silage in dry years.

Corn silage is typically the main forage on dairy farms in New York due to its high yield and energy content for optimized milk production. Studies elsewhere have shown that forage sorghum can have comparable yields to corn silage (Marsalis et al., 2010). Evaluations of forage sorghum yield and nutritive value compared to corn silage grown under soil and weather conditions in the Northeast are needed. In years such as 2015, 2016, and 2017 in New York, for example, with delayed corn planting because of exceptionally wet springs, and, in some years, drought conditions during mid-summer (NRCC, 2016), forage sorghum would likely have competed with corn silage for both yield and nutrients.

Typically, conventional forage sorghum varieties outperformed BMR sorghum varieties in yield (Oliver et al., 2005; Marsalis et al., 2009; Marsalis et al., 2010). For example, Marsalis et al. (2010) reported a 13% lower yield for BMR forage sorghum compared to a conventional variety (21.1 vs 24.4 Mg DM ha^{-1}, respectively). However, breeding improvements in the past 10-to-15 years have resulted in new varieties of BMR forage sorghum with the brachytic dwarf trait (Oliver et al., 2005) that can compete in yield with conventional varieties. Brachytic dwarf varieties have higher leaf-to-stem ratios, increased tillering, and shortened internodes, which support greater yields and greater digestibility while also reducing the risk of lodging (Pendleton and Seif, 1961).

For more recently developed varieties, the nutritive value of BMR forage sorghum is comparable to that of corn silage for most components (Grant et al., 1995; Aydin et al., 1999; Marsalis et al., 2010) except for starch concentration, which is often lower in forage sorghum than in corn silage (Oliver et al., 2004; Harper et al., 2017), reflecting harvest at the soft-dough stage or earlier. Thus, energy supplements might be needed for forage sorghum-based rations.

The impact of using forage sorghum as an alternative to corn silage in dairy diets has been evaluated primarily in the midwest United States. In Nebraska, Aydin et al. (1999) observed that the primary differences between BMR sorghum-, conventional sorghum-, and corn silage-based TMRs were their lignin, ADF, and NDF concentrations, as well as the amount of rolled corn and soybean meal included. Conventional and BMR sorghum TMRs had less rolled corn (10.7% DM) and more soybean meal (21.5% DM) than corn silage TMR (11.4% rolled corn and 20.8% soybean meal), while the corn silage-based TMR had the lowest concentrations of lignin (3.3% DM), followed by BMR sorghum (5.2% DM) and conventional sorghum (6.4% DM) (Aydin et al., 1999). The diet with BMR sorghum performed similarly to the diet with corn silage as the main forage and was superior to the diet based on conventional sorghum in terms of milk production and forage digestibility. Another study in Nebraska also found that cows fed a BMR sorghum-based TMR performed similarly to those fed a corn silage-based TMR while providing for more milk and milk components than cows fed a conventional sorghum-based TMR (Grant et al., 1995). Starch concentrations for these studies were not reported. However, in both of these studies, forage sorghum was harvested at the hard-dough stage, which is later than recommended for sorghum forage production in New York. A third study in

Nebraska that compared 2 hybrids of BMR forage sorghum (BMR-6 and -18) with conventional sorghum and corn silage had findings consistent with those by Aydin et al. (1999) and Grant et al. (1995), including lower lignin in sorghum-based diets and milk production of cows similar to the corn silage-based diet fed cows (Oliver et al., 2004). A recent study in Pennsylvania showed that DM intake, milk yield, and milk protein decreased while milk fat and energy-corrected milk yield increased with partial replacement of corn silage with BMR forage sorghum harvested at the milk stage in a dairy TMR (Harper et al., 2017). The authors did not adjust the baseline diet beyond replacing 10% of the corn silage in the diet with sorghum silage. The lower starch content of the immature sorghum likely played a part in reduced milk yields. Addition of energy supplements may be needed to avoid milk yield decline.

Oliver et al. (2004) reported differences in starch and 48-h NDFD ($NDFD_{48}$) concentrations among sorghum- and corn silage-based diets as well. Starch was greatest in the corn silage (19.9% DM), intermediate for BMR-6 (16.8% DM) and BMR-18 (14.5% DM) sorghum, and the least in conventional sorghum (10.9% DM). The $NDFD_{48}$ of the BMR-6 sorghum (62.4%), BMR-18 sorghum (61.0%), and corn silage (59.1%) were not different but were greater than the conventional sorghum (56.4%) (Oliver et al., 2004).

In addition to variety selection, stage of maturity at harvest can impact both the yield and nutritive value of forage sorghum. A study with BMR forage sorghum in Israel reported that when the sorghum was harvested at early heading, DM and lignin concentrations were reduced compared to sorghum harvested at the soft dough stage (Miron et al., 2006). Dry matter yield, NDF, and $NDFD_{48}$, however, were not different between the 2 growth stages. A similar forage sorghum study in Turkey found that yield, as well as concentrations of DM and lignin, increased with maturity, while CP, NDF, and ADF concentrations decreased (Atis et al., 2012), leading to a recommendation to delay forage sorghum harvest until the soft dough stage when DM concentration is greater. However, while low DM concentrations can impact silage quality and increase risk of silage leachate, inoculant use (Filya, 2003) and adjustments in forage chop length can facilitate proper ensiling even if forages are relatively low in DM concentration. Mowing and wilting forage sorghum to reduce moisture has been used in the Midwest to increase forage sorghum DM (Grant et al., 1995). However, this practice has not been tested in the humid Northeast. Harvest of forage sorghum before the soft dough stage to facilitate timely planting of a winter cereal in the Northeast might be feasible, but research is needed to determine impact of timing of harvest of the sorghum on tradeoffs between forage yield and quality.

The objective of this study is to determine whether brachytic dwarf BMR forage sorghum grown in New York can be harvested before the soft dough stage, to allow for an earlier winter cereal double crop planting, while maintaining yield, nutritive value, and ration performance.

MATERIALS AND METHODS

Locations and Experimental Design

Seven field trials were established at 2 locations from 2014 to 2017. Four trials were conducted at the Musgrave research farm in Aurora, NY (42.73°N, -76.66°W) in 2014 (trial 1), 2015 (trial 2), 2016 (trial 3), and 2017 (trial 4). The soil type was a

Lima silt loam (fine-loamy, mixed, semiactive, mesic Oxyaquic Hapludalfs) classified as soil management group 2 (Ketterings et al., 2003). Three trials were conducted at the Pullyen-Tailby research farm in Tompkins county, NY (42.43°N, -73.67°W) in 2014 (trial 5), 2015 (trial 6), and 2017 (trial 7). The trial in 2016 at this location failed to emerge due to a severe lack of precipitation following planting. The soil type was a mix of Hudson silt loam (fine, illitic, mesic Glossaquic Hapludalfs) and collamer silt loam (Fine-silty, mixed, semiactive, mesic Glossaquic Hapludalfs), classified as soil management group 3 (Ketterings et al., 2003).

Trials were organized in a randomized complete block design with repeated measures in 4 replications. Treatments included 4 timings of harvest and 2 N rates broadcasted (surface-applied) at planting (112 and 224 kg N ha^{-1}) as Agrotain®-treated urea (Koch Agronomic Services, LLC, Wichita, KS). Harvests were repeated in the same plots across 4 weeks.

Weather data were collected from an on-site weather station for the Musgrave farm, and the Cornell University weather station in Tompkins County, NY, approximately 5 km from the Pullyen-Tailby farm. Precipitation was consistent with the 30-year average in 2014 and 2015. Precipitation was greater than normal in late spring and early summer of 2017, and lower than normal in spring and early summer in 2016 (Table 6.1).

Table 6.1. Monthly precipitation and temperature for seven brown mid-rib (BMR) forage sorghum trials in New York from 2014 to 2017. Data were obtained from within-county weather stations (NRCC, 2016). The average monthly temperature is determined from calculated daily averages [(maximum daily temperature – minimum daily temperature)/2].

Trial	County	Year	June	July	August	September	October
Total monthly precipitation			-------------------------------		cm		-------------------------------
1	Cayuga	2014	7.3	11.7	11.3	5.9	6.5
2		2015	20.3	7.1	3.5	13.2	7.2
3		2016	2.8†	4.8†	11.6†	9.6†	20.5
4		2017	9.7	18.6	3.8	6.6	15.2
5	Tompkins	2014	13.1	9.8	15.4	5.6	7.6
6		2015	16.7	12.5	3.6	10.1	5.6
7		2017	9.4	16.9	6.0	5.6	17.9
Average monthly temperature			-------------------------------		°C		-------------------------------
1	Cayuga	2014	19.1	20.3	19.0	16.1	11.6
2		2015	17.8	20.4	19.8	19.2	9.9
3		2016	18.6	22.1	22.8	18.2	11.5
4		2017	17.8	20.4	19.8	19.2	9.9
5	Tompkins	2014	18.4	19.9	18	15.4	10.8
6		2015	17.6	19.6	19.4	18.4	9.0
7		2017	17.6	19.6	19.4	18.4	9.0

†2-7 days of missing data.

Planting and Harvest

All plots were prepared with primary (chisel plow) and secondary (disc) tillage prior to planting. A brachytic dwarf BMR-6 forage sorghum cultivar (AF7102, Alta Seeds, Irving, TX) adapted to the northeastern USA was planted with a 4-m conventional drill at 17 kg ha^{-1} and 3 cm depth in 38 cm row spacing followed by rolling. Planting dates ranged from 3 June to 2 July (Table 6.2). The most economic rates of N (MERNs) were calculated for each trial by fitting a quadratic plateau model to the yield response data (5 rates of N), as reported in Lyons et al. (2019). A fertilizer cost of \$1.54 per kg of N and forage value of \$108.86 per Mg silage were used to determine the MERN (Lyons et al., 2019). In short, for trials 1 and 6 the MERN exceeded the 224 kg N ha^{-1} rate while MERNs in the 2 other Tompkins County trials (trials 5 and 7) were 157 and 150 kg N ha^{-1}, respectively. The 3 other Cayuga County trials had MERNs of 241, 229, and 262 kg N ha^{-1} for trials 2, 3, and 4, respectively. Thus, while the highest of the selected N rates (224 kg N ha^{-1}) for the assessment of timing of harvest on yield and nutritive value met or exceeded the MERN for 3 of the trials, for the other 4 trials an increased N rate could have resulted in somewhat greater yields.

Table 6.2. Planting and harvest dates for seven brown mid-rib (BMR) forage sorghum trials in New York from 2014 to 2017. Sorghum was hand-harvested at four different growth stages (boot, flower, milk, and soft dough).

				------------- Growth stage at harvest -------------			
Trial	County	Year	Planting	Boot	Flower	Milk	Soft dough
1	Cayuga	2014	20 June	18 Sept.	23 Sept.	2 Oct.	9 Oct.
2		2015	2 July	3 Sept.	18 Sept.	16 Oct.	30 Oct.
3		2016	3 June	15 Aug.	23 Aug.	na†	20 Sept.
4		2017	12 June	24 Aug.	1 Sept.	26 Sept.	5 Oct.
5	Tompkins	2014	21 June	15 Sept.	22 Sept.	1 Oct.	6 Oct.
6		2015	12 June	27 Aug.	17 Sept.	1 Oct.	14 Oct.
7		2017	9 June	22 Aug.	30 Aug.	19 Sept.	2 Oct.

†na, not applicable.

Sorghum was harvested at 4 growth stages: boot (stage 5), flower (stage 6), milk (stage 6.5), and soft dough (stage 7) (Vanderlip and Reeves, 1972). Trial 3 did not include a milk stage harvest due to an adjustment in protocol in 2016. In 2017 the milk stage harvest was added again. Harvest was completed by hand using a 10-cm cutting height and a 1.5 m × 4 row harvest area, or approximately 1.5 m^2 (1.5 × 1.5 m), per plot. Given inconsistent stands in some of the trials, gaps between individual plants in a row greater than approximately 30 cm were recorded and area harvested was adjusted accordingly (Lyons et al., 2019).

Soil and Forage Sampling and Analysis

Prior to fertilization, 2 soil cores (0-20 cm depth) were taken in each plot and composited by replication (Table 6.3). Soil composites were dried at 50°C and ground to pass a 2-mm screen. Samples were submitted for both baseline fertility analysis (Analytical Laboratory and Maine Soil Testing Service, Orono, ME; Table 6.3) and Morgan extracted NO_3-N (Nutrient Management Spear Program Laboratory, Ithaca, NY).

Table 6.3. Baseline soil fertility status for seven brown mid-rib (BMR) forage sorghum trials in New York from 2014 to 2017. Values are averages of four, 0- to 20-cm core soil composites within each field.

Trial	County	Year	pH	SOM†	Morgan-P‡	Morgan-K‡	Morgan-Mg‡
				%	----------------------	mg kg^{-1}	---------------------
1	Cayuga	2014	7.7	2.2	5.2 (H)	59 (H)	282 (VH)
2		2015	7.5	2.4	7.1 (H)	58 (H)	225 (VH)
3		2016	8.0	2.4	5.3 (H)	51 (H)	305 (VH)
4		2017	7.9	2.3	5.3 (H)	70 (H)	337 (VH)
5	Tompkins	2014	5.9	2.7	18.7 (H)	288 (VH)	137 (VH)
6		2015	5.6	2.0	17.0 (H)	150 (VH)	90 (H)
7		2017	6.1	2.5	19.2 (H)	162 (VH)	168 (VH)

†Soil organic matter (SOM) determined by loss-on-ignition (Storer, 1984).
‡Morgan extraction (Morgan, 1941); L = low, M = medium, H = high, and VH = very high according to Cornell Cooperative Extension (2018).

Soil pH was measured in a 1:1 (w/v) water extract, and soil organic matter (SOM) was determined by loss-on-ignition through exposure to 500°C for 2 hours (Storer, 1984). The Cornell Morgan soil test was used to extract P, K, Mg, Ca, Mn, and Zn by shaking dried samples in a 1:5 (v/v) ratio Morgan solution (1 M sodium acetate buffered at pH 4.8; Morgan, 1941) for 15 min. The extracts were filtered through a Whatman No. 2 equivalent filter paper following procedures outlined in NEC-1012 (Northeast Coordinating Committee for Soil Testing, 2011). The filtered extracts were analyzed for K, Mg, Ca, Mn, and Zn using an inductively coupled plasma atomic emission spectrometer (ICP-AES, JY70 Type II, Jobin Yvon, Edison, NJ). Phosphorus was determined colorimetrically using the ammonium molybdate-ascorbic acid method (Knudsen and Beegle, 1988) with a Lachat QuikChem® 8000 flow injection analyzer (Lachat Instruments, Milwaukee, WI). The Morgan extraction (Morgan, 1941) was used to extract soil NO_3-N followed by determination of NO_3-N in solution with a discrete analyzer (EasyChem Plus, Chinchilla Scientific, LLC, Oak Brook, IL). Soil pH for all trials ranged from 5.9 to 8.0. Although a soil pH of 6.0 is often recommended for sorghum, it will grow at a pH as low as 5.5 (Teutsch, 2009), and thus soil pH was unlikely to significantly impact performance. Soil organic matter ranged from 20 to 27 g kg^{-1}. Soil test P, K, and Mg were classified as high or very high, and Mn was normal for all trials according to Cornell Cooperative Extension (2018).

Plants were coarsely ground using a leaf shredder-chipper (MacKissic Inc., Parker Ford, PA), subsampled, placed in sealed plastic bags, and kept cold until reaching the laboratory for drying. Forage subsamples were dried in a forced-air oven at approximately 55°C until stable weights were reached and DM concentrations were determined. Dried samples were ground with a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen and submitted to Cumberland Valley Analytical (Waynesboro, PA) for analysis with a Foss 5000 NIR. Total forage N was multiplied by 6.25 to determine CP concentration following Method 46-10.01 of AACC (AACC International, 1999).

Diet Simulation

The Cornell Net Carbohydrate and Protein System v. 6.55 (Van Amburgh et al., 2015) was used to evaluate the impact of corn silage substitution by forage sorghum in a typical dairy TMR on metabolizable energy and protein allowable milk. The control diet was a corn silage-based TMR (Table 6.4). The BMR forage sorghum was substituted for 0, 25, 50, 75, and 100% of corn silage in the diet to demonstrate the impact ration changes on ME allowable milk and milk protein (MP) allowable milk. No adjustments for DM intake were considered in this evaluation, although changes in NDFD could affect feed intake (Kendall et al., 2009).

Table 6.4. Cornell Net Carbohydrate and Protein System (CNCPS) input parameters for a typical dairy total mixed ration. Brown mid-rib (BMR) forage sorghum sample analyses from seven trials in New York from 2014 to 2017 were substituted for different percentages of corn silage in the diet.

Animal inputs	
Milk production	40 kg d^{-1}
Mature weight	750 kg
Age	42 mo
Days since calving	120 d
Inputted DM[†] intake	26.0 kg DM d^{-1}
Predicted DM[†] intake	23.1 kg DM d^{-1}
Diet input[‡]	% of diet
Corn silage (30% DM, 41% NDF[†]) and/or BMR sorghum[§]	38.5
Alfalfa silage (20% CP[†], 40% NDF, 17% LNDF[†])	17.3
Corn grain (ground fine)	17.3
Soybean meal	5.8
Soybean hulls	5.8
Cottonseed (fuzzy)	3.8
Soy Plus	3.8
Citrus pulp (dry)	1.9
Corn gluten feed (dry)	1.9
Blood meal	0.8
MinVit	2.7
Trace mineral premix	0.4

[†]DM: dry matter; NDF: neutral detergent fiber; CP: crude protein; LNDF:
[‡]All diet inputs except for BMR sorghum are derived from the CNCPS library.
[§]Control diet contains corn silage only. Treatment diets substitute BMR forage sorghum for 0, 50, and 100% of corn silage.

Statistical Analysis

For both locations, initial analyses with PROC MIXED of SAS with the Tukey adjustment for multiple comparisons (SAS Institute, 1999) showed there was a significant interaction between growth stage and year for all nutritive value parameters. For yield, there was a significant interaction between growth stage and year for the Tompkins County trials, and a significant effect of year for the Cayuga County trials. Because of this, trials were analyzed individually (by location and year) using PROC MIXED of SAS v. 9.4 with the Tukey adjustment for multiple comparisons (SAS Institute, 1999). If the interaction between N rate and timing of harvest was not significant, main effects were determined and presented. Significance is defined as $P \leq 0.05$.

RESULTS AND DISCUSSION

Nitrogen Rate, Yield, and Forage Nutritive Value

There was no interaction between timing of harvest and N rate for yield ($P \geq 0.1991$; Table 6.5). Yield at the higher N rate and soft dough stage of harvest ranged from 14.1 Mg DM ha^{-1} (trial 5) to 19.5 Mg DM ha^{-1} (trial 7). As mentioned, yields for 4 of the trials would have been somewhat greater with a higher N application, as MERNs for these 4 sites exceeded 224 kg N ha^{-1}.

Table 6.5. Impact of N rate and timing of harvest on yield, dry matter (DM), and forage nutritive value parameters.

Trial	Timing	N rate	Int.	Timing	N rate	Int.	Timing	N rate	Int.
		Yield			*aNDFom*†			*Starch*	
1	< 0.0001	0.0035	0.9742	< 0.0001	0.8414	0.2619	< 0.0001	0.0551	0.8027
2	< 0.0001	0.0014	0.4080	0.0023	0.5332	0.3135	< 0.0001	0.0029	0.0011
3	< 0.0001	0.5151	0.7563	< 0.0001	0.7235	0.2509	< 0.0001	0.7729	0.9148
4	0.0014	0.1391	0.3807	< 0.0001	0.0708	0.4218	< 0.0001	0.7626	0.6640
5	0.0166	0.1685	0.1991	0.0170	0.7063	0.5441	< 0.0001	0.6028	0.9752
6	0.0002	0.0182	0.6278	< 0.0001	0.4857	0.8849	< 0.0001	0.5780	0.7971
7	< 0.0001	0.9060	0.9438	< 0.0001	0.1396	0.4142	< 0.0001	0.9313	0.5522
		DM			*ADF*†			*TDN*†	
1	0.0001	0.0010	0.6643	< 0.0001	0.3671	0.3732	0.0008	0.0400	0.8861
2	< 0.0001	0.0031	0.5745	< 0.0001	< 0.0001	0.3772	< 0.0001	< 0.0001	0.4400
3	0.0002	0.7830	0.7128	< 0.0001	0.2103	0.2918	< 0.0001	0.0459	0.3707
4	< 0.0001	0.4612	0.4477	< 0.0001	0.0078	0.7567	0.0012	0.0015	0.9526
5	< 0.0001	0.0002	0.5116	0.0014	0.2878	0.5134	< 0.0001	0.0499	0.3022
6	0.0019	0.1919	0.8716	< 0.0001	0.0892	0.8040	< 0.0001	0.2077	0.7806
7	< 0.0001	0.5198	0.3029	< 0.0001	0.0767	0.4672	0.0017	0.0928	0.4660
		CP†			*$NDFD_{30}$*†			*NFC*†	
1	0.0317	0.0011	0.7879	< 0.0001	0.5369	0.6977	< 0.0001	0.1416	0.2614
2	< 0.0001	< 0.0001	0.6732	< 0.0001	0.0257	0.0586	< 0.0001	0.1543	0.9275
3	< 0.0001	0.0149	0.3442	< 0.0001	0.6147	0.9766	< 0.0001	0.8415	0.8299
4	< 0.0001	0.0043	0.9973	< 0.0001	0.2580	0.7540	< 0.0001	0.4232	0.7405
5	0.1358	< 0.0001	0.7519	< 0.0001	0.0790	0.9514	0.0068	0.1268	0.4195
6	< 0.0001	0.0085	0.7277	< 0.0001	0.9809	0.5300	< 0.0001	0.6602	0.5118
7	< 0.0001	0.0003	0.1981	< 0.0001	0.6693	0.5764	< 0.0001	0.9198	0.3131

†CP: crude protein; aNDFom: neutral detergent fiber (organic matter basis with amylase); ADF: acid detergent fiber; $NDFD_{30}$: neutral detergent fiber digestibility (30 h); TDN: total digestible nutrients; NFC: non-fiber carbohydrates.

These yields are similar to or greater than those reported by Miron et al. (2005) for irrigated BMR forage sorghum harvested at soft dough stage in Israel (averaging 15.3 Mg DM ha^{-1}) and the yields of a non-irrigated study in Nebraska that ranged from 9.7 to 13.5 Mg DM ha^{-1} when harvested at the hard dough stage (Oliver et al., 2004). Another irrigated study in New Mexico reported BMR forage sorghum yields of 21.1 Mg DM ha^{-1} when harvested at the soft dough stage (Marsalis et al., 2010). Irrigation is not often used in New York due to typically high amounts of rainfall in the Northeast, which could explain yield differences between drier years in New York and yields in the irrigated, drier climate of New Mexico as described by Marsalis et al. (2010).

The impact of fertilizer N rate (112 vs 224 kg N ha^{-1}) on yield and forage nutritive value varied among trials (Table 6.5). There was a main effect of N rate on yield for 3 trials (trials 1, 2, and 6) and DM for 3 trials (trials 1, 2, and 5), consistent with the fact that for these trials the MERN was greater than the 224 kg N ha^{-1} rate (Lyons et al., 2019). For these trials, the 112 kg N ha^{-1} rate resulted in lower DM yield and greater DM at harvest (Table 6.5). Most sorghum research has been conducted in dryland or irrigated cropping systems (Leikam et al., 2003; Westfall and Davis, 2005; Marsalis et al., 2010) and literature on N management of forage sorghum is scant. Thus, research across climates and soil resources is needed to allow for a direct comparison of N needs with values reported in the literature. Although forage nitrate-N was not measured, it should be considered when feeding sorghum as nitrate toxicity is a potential issue for this crop (Adams et al., 1992). However, nitrate-N is usually reduced during the ensiling process as much of it is converted to nitrogen dioxide

(Undersander et al., 1999).

There were no interactions between harvest timing and N rate for CP. For all trials, the 112 kg N ha^{-1} N rate resulted in lower CP concentrations than the 224 kg N ha^{-1} rate. On average for the soft dough stage, CP ranged from 75 to 85 g kg^{-1} for the 112 and 224 kg N ha^{-1} rates, respectively. This range is similar to BMR sorghum CP found in other studies, which ranged from 63 to 97 g kg^{-1} (Grant et al., 1995; Aydin et al., 1999; Oliver et al., 2004; Miron et al., 2005; Miron et al., 2006; Marsalis et al., 2010).

There was an interaction between time of harvest and N rate for starch content for 1 trial (trial 2). For this trial, there was a greater increase in starch content from the boot to the soft dough stage for the 224 kg N ha^{-1} treatment (70 to 174 g kg^{-1}, respectively) than for the 112 kg N ha^{-1} treatment (78 to 131 g kg^{-1}, respectively). For all other trials there was no impact of N rate on starch concentrations; starch content ranged from 94 to 230 g kg^{-1} when harvested at the soft dough stage.

There was no interaction between N rate and timing of harvest for any of the other forage quality parameters (Table 6.5). Impact of N rate on forage quality indicators was inconsistent among trials. The 224 kg N ha^{-1} rate had decreased ADF content for trials 2 (287 vs. 301 g kg^{-1}) and 4 (275 vs. 292 g kg^{-1}), decreased $NDFD_{30}$ for trial 2 (645 vs. 653 g kg^{-1}), and increased TDN content for trials 1 (667 vs. 663 g kg^{-1}), 2 (699 vs. 690 g kg^{-1}), 3 (693 vs. 688 g kg^{-1}), 4 (704 vs. 693 g kg^{-1}), and 5 (672 vs. 667 g kg^{-1}). The same quality parameters were not impacted by N rate for the other trials and N rate did not impact aNDFom or NFC at any of the sites either. Findings for NDF content and NDFD are consistent with Marsalis et al. (2010) who reported that NDF content and NDFD were not impacted by N rate when 2 N rates were applied (196 and 230 kg N ha^{-1}). However, it is not known what the MERN was for these specific trials in comparison to the 2 rates of N used in the current study.

Harvest Timing and Yield

Timing of harvest impacted yield for all trials (Table 6.6 and Figure 6.1). For 4 of the trials, DM yield did not increase past the flower stage (trials 1, 2, 5, and 6). For trial 4, DM yield was maximized at the milk stage, while sorghum in trials 3 and 7 continued to increase in DM yield until the soft dough stage. Dry matter yield across trials averaged 10.7, 13.5, 15.2, and 15.8 Mg DM ha^{-1} for the boot, flower, milk, and soft dough stages, respectively. A study in Turkey observed a similar increase in forage sorghum DM yield with maturity, ranging from 10.3 Mg DM ha^{-1} at the panicle emergence stage (between boot and flowering) to 21.1 Mg DM ha^{-1} at the soft dough stage (Atis et al., 2012). The study by Atis et al. (2012) showed a greater increase in DM with maturity most likely reflecting the drier climate in Turkey as compared to New York.

Table 6.6. Dry matter (DM) yield, DM, and crude protein (CP) for seven brown mid-rib (BMR) forage sorghum trials in New York from 2014 to 2017. Harvest took place at four growth stages, and two rates of N (112 and 224 kg N ha^{-1}) were applied at planting.

Trial	Boot	Flower	Milk	Soft dough	SE	*P*
Yield†	------------------------------ Mg DM ha^{-1} ----------------------------					
1	10.9 b	13.7 a	14.3 a	15.7 a	0.6	0.0001
2	9.9 b	16.2 a	18.1 a	18.1 a	0.6	< 0.0001
3	8.1 c	10.1 b	na‡	16.3 a	0.5	< 0.0001
4	11.1 b	12.4 b	14.8 a	12.4 b	0.6	0.0002
5	10.9 b	12.1 ab	12.9 ab	14.1 a	0.7	0.0220
6	10.1 b	13.9 a	14.3 a	14.7 a	0.7	0.0004
7	13.9 c	15.9 b	16.5 b	19.5 a	0.5	< 0.0001
DM†	-------------------------------- g kg^{-1} --------------------------------					
1	221 c	259 ab	244 b	270 a	3.0	< 0.0001
2	215 c	266 b	290 a	302 a	4.0	< 0.0001
3	201 b	208 b	na‡	293 a	7.0	< 0.0001
4	203 c	241 b	274 a	291 a	4.0	< 0.0001
5	221 c	258 a	243 b	238 b	2.0	0.0015
6	238 b	284 a	272 ab	303 a	7.5	< 0.0001
7	190 d	217 c	241 b	267 a	5.0	< 0.0001
CP†	------------------------------ g kg^{-1} DM ------------------------------					
1	91 a	80 a	85 a	75 a	3.6	0.0780
2	102 a	94 b	76 c	77 c	1.9	< 0.0001
3	129 a	117 b	na‡	91 c	1.4	< 0.0001
4	99 a	87 ab	76 bc	68 c	3.4	< 0.0001
5	76 a	80 a	80 a	86 a	2.8	0.3777
6	116 a	96 b	85 b	83 b	3.8	< 0.0001
7	118 a	105 b	90 c	84 d	1.4	< 0.0001

†DM: dry matter; CP: crude protein; Different lower-case letters among growth stages within year and trial represent significant differences ($P \leq 0.05$).
‡na, not applicable.

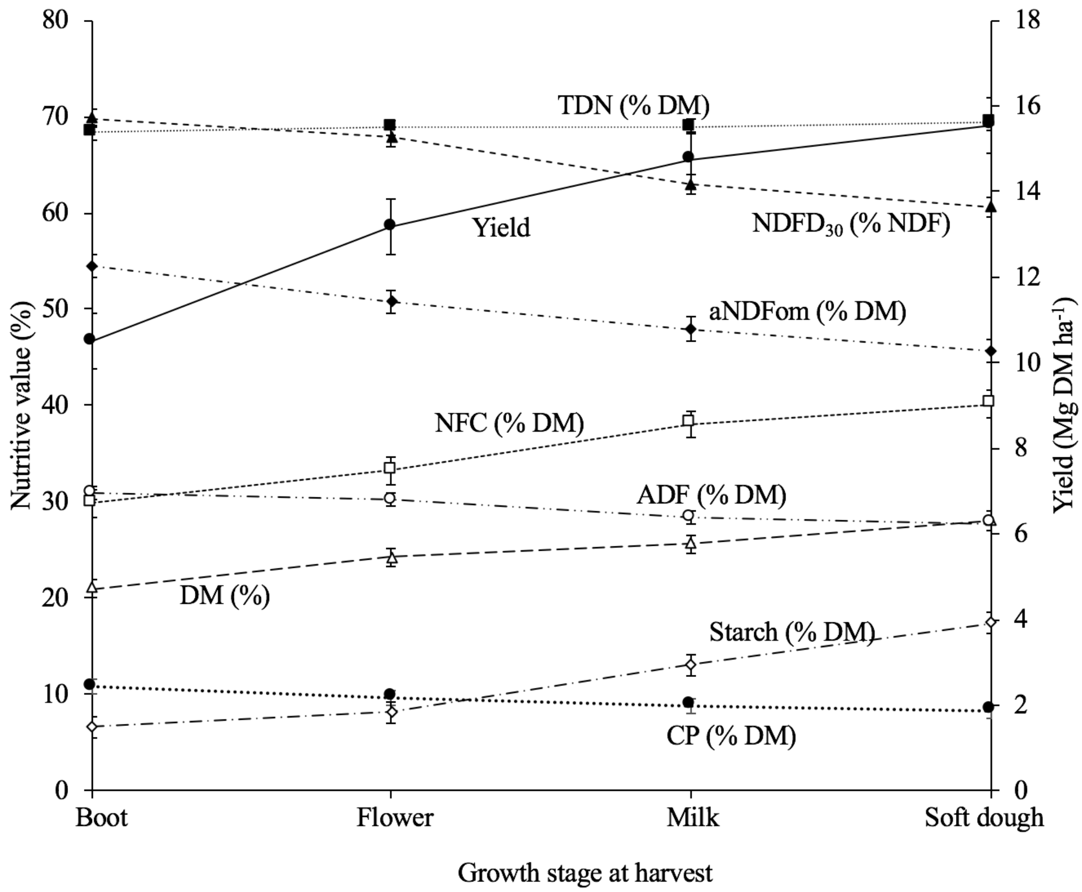

Figure 6.1. Summary of yield and total digestible nutrients (TDN), neutral detergent fiber digestibility (30 h; $NDFD_{30}$), neutral detergent fiber (NDF), non-fiber carbohydrates (NFC), acid detergent fiber (ADF), dry matter (DM), and crude protein (CP) as impacted by growth stage at harvest for thirteen brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Neutral detergent fiber was analyzed on an organic matter basis with amylase. Error bars represent 1 SE.

Two studies comparing forage sorghum yield, DM, and forage quality at different growth stages stated that DM was much lower at the early growth stages compared to soft dough, resulting in the recommendation to delay harvest until the soft dough stage (Miron et al., 2006; Atis et al., 2012). In our study, DM increased with later harvests when averaged across trials (Table 6.6) but individual trials differed in their response. For 3 trials (trials 1, 5, and 6), DM concentration did not increase beyond the flower stage. For 2 trials (trials 2 and 4), DM increased until the milk stage, while for 2 trials (trials 3 and 7), DM was maximized at the soft dough stage. On average across all trials, DM was to 213, 249, 258, and 280 g kg^{-1} for the boot, flower, milk, and soft dough stages, respectively. Given the lower DM content of these forages, management strategies such as use of bacterial inoculants could aid the ensiling process (Filya, 2003).

Harvest Timing and Forage Nutritive Value

For one trial CP was not impacted by harvest timings (trial 5; $P = 0.3777$) (Table 6.6). All other trials decreased in CP with maturity or showed a similar trend (trial 1; $P = 0.0780$). On average across all trials, CP was 104, 94, 82, and 81 g kg^{-1} DM at the boot, flower, milk, and soft dough stages, respectively. These results are consistent with findings by Miron et al. (2006) which showed a decrease in CP from 79 g kg^{-1} DM at early heading to 73 g kg^{-1} g kg^{-1} DM at the soft dough stage of BMR sorghum. Atis et al. (2012) also reported a decrease in CP with increasing maturity, ranging from 83 g kg^{-1} at panicle emergence to 77 g kg^{-1} at the soft dough stage.

Later harvest timings resulted in decreased aNDFom, ADF, and $NDFD_{30}$ for all trials (Table 6.7). For aNDFom, trials 1 and 6 were lowest for sorghum harvested at the soft dough stage, trials 2, 4, and 7 decreased in aNDFom until the milk stage, and trials 3 and 5 decreased in aNDFom until the flower stage. On average, aNDFom decreased from 547 g kg^{-1} DM at the boot stage to 458 g kg^{-1} DM at the soft dough stage, a decrease of 38 g kg^{-1} DM from the boot to the flower stage, 27 g kg^{-1} DM from the flower to the milk stage, and 25 g kg^{-1} DM from the milk to the soft dough stage while starch content increased. This NDF decrease was also observed in the studies by Miron et al. (2006) and Atis et al. (2012), who documented an average decrease with maturity of 73 g kg^{-1}. In our study, ADF decreased by 11 g kg^{-1} DM per growth stage. The maximum $NDFD_{30}$ occurred at the boot and flower stages for trials 1, 3, and 5, and at the boot stage for trials 2, 4, 6, and 7. On average, $NDFD_{30}$ decreased from 698 g kg^{-1} NDF at the boot stage to 606 g kg^{-1} NDF at the soft dough stage, an average decrease of 31 g kg^{-1} NDF per growth stage.

Table 6.7. Forage fiber characteristics for seven brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Two rates of N (112 and 224 kg N ha^{-1}) were applied at planting. Harvest took place at four growth stages.

Trial	Boot	Flower	Milk	Soft dough	SE	P
aNDFom†	------------------------------ g kg^{-1} DM† ------------------------------					
1	556 a	536 b	531 b	476 c	6.3	< 0.0001
2	523 a	514 ab	456 bc	446 c	1.6	0.0019
3	563 a	455 b	na‡	444 b	1.6	< 0.0001
4	544 a	501 b	473 c	459 c	6.6	< 0.0001
5	560 a	529 b	525 b	531 ab	7.6	0.0118
6	513 a	516 a	487 b	397 c	1.1	< 0.0001
7	570 a	516 b	458 c	452 c	6.1	< 0.0001
ADF†	------------------------------ g kg^{-1} DM† ------------------------------					
1	322 a	318 a	312 a	286 b	4.0	< 0.0001
2	37 a	308 a	269 c	292 b	2.9	< 0.0001
3	312 b	324 a	na‡	260 c	2.8	< 0.0001
4	304 a	283 b	277 b	272 b	4.0	< 0.0001
5	329 a	306 b	308 b	307 b	4.0	0.0010
6	286 ab	295 a	272 bc	265 c	3.9	< 0.0001
7	313 a	286 b	265 c	264 c	3.3	< 0.0001
$NDFD_{30}$†	------------------------------- % NDF --------------------------------					
1	70 a	71 a	66 b	67 b	0.425	< 0.0001
2	71 a	68 b	61 c	59 d	0.378	< 0.0001
3	71 a	70 a	na‡	58 b	0.474	< 0.0001
4	70 a	67 b	62 c	59 d	0.255	< 0.0001
5	69 a	68 a	67 b	66 b	0.315	< 0.0001
6	70 a	66 b	59 c	56 d	0.501	< 0.0001
7	69 a	67 b	63 c	60 d	0.364	< 0.0001

†aNDFom: neutral detergent fiber (organic matter basis with amylase); DM: dry matter; ADF: acid detergent fiber; $NDFD_{30}$: neutral detergent fiber digestibility (30 h); Different lower-case letters among growth stages within year and location represent significant differences ($P \leq 0.05$).
‡na, not applicable.

Starch was maximized at more mature growth stages (Table 6.8), and on average increased by 16 g kg^{-1} DM from the boot to the flower stage, 47 g kg^{-1} DM from the flower to the milk stage, and 43 g kg^{-1} DM from the milk to the soft dough stage. For 5 of the trials, the highest starch concentrations were obtained at the soft dough stage, while sorghum did not increase in starch beyond the milk stage for trial 2 and the flower stage for trial 5. Thus, in most cases, harvesting before the soft dough stage resulted in lower starch concentrations. These findings are consistent with a study by Miron et al. (2006) where the authors concluded that with increasing BMR forage sorghum maturity, whole plant water soluble carbohydrate (WSC) concentrations decreased from 280 g kg^{-1} DM at the early heading stage to 138 g kg^{-1} DM at the soft dough stage. This was attributed to an increase in starch with grain maturation reflecting a conversion of WSC to starch (Miron et al., 2006). The response of starch to timing of harvest was also reflected in NFC, with most trials having the highest NFC concentration at the milk or soft dough stages (Table 6.8).

Table 6.8. Forage starch, total digestible nutrients (TDN), and non-fiber carbohydrates (NFC) on a dry matter (DM) basis for seven brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Two rates of N (112 and 224 kg N ha^{-1}) were applied at planting. Harvest took place at four growth stages.

Trial	Boot	Flower	Milk	Soft dough	SE	*P*
Starch†	--------------------------------	g kg^{-1} DM	--------------------------------			
1	66 c	81 b	79 b	116 a	2.43	< 0.0001
2	74 b	90 b	153 a	152 a	6.03	< 0.0001
3	41 b	48 b	na‡	229 a	6.43	< 0.0001
4	66 d	90 c	144 b	194 a	4.16	< 0.0001
5	73 b	92 a	93 a	94 a	2.77	< 0.0001
6	85 c	96 c	186 b	230 a	7.59	< 0.0001
7	59 d	82 c	125 b	193 a	4.85	< 0.0001
TDN†	--------------------------------	g kg^{-1} DM	--------------------------------			
1	665 b	661 b	661 b	673 a	1.97	0.0008
2	687 c	688 c	708 a	697 b	1.83	< 0.0001
3	680 b	677 b	na‡	715 a	2.09	< 0.0001
4	696 b	706 a	691 b	693 b	2.74	0.0022
5	659 c	682 a	671 b	666 bc	2.59	< 0.0001
6	698 bc	691 c	704 b	714 a	2.12	< 0.0001
7	692 b	706 a	695 b	696 b	2.32	0.0018
NFC†	--------------------------------	g kg^{-1} DM	--------------------------------			
1	308 c	337 b	343 b	400 a	6.50	< 0.0001
2	317 c	335 c	434 b	398 a	5.91	< 0.0001
3	265 b	270 b	na‡	424 a	6.76	< 0.0001
4	324 c	379 b	410 a	431 a	5.16	< 0.0001
5	310 b	346 a	343 a	343 a	7.78	0.0073
6	320 b	341 b	400 a	422 a	6.74	< 0.0001
7	278 c	348 b	407 a	425 a	6.11	< 0.0001

†TDN: total digestible nutrients; NFC: non-fiber carbohydrates; Different lower-case letters among growth stages within year and location represent significant differences ($P \leq 0.05$).
‡na, not applicable.

While TDN was impacted by growth stage at harvest, for 3 trials there was no difference in TDN between the boot and soft dough stages (trials 4, 5, and 7; 688 g TDN kg^{-1} DM average), 3 had the highest TDN at the soft dough stage (trials 1, 3, and 6; 700 g TDN kg^{-1} DM average), and 1 had maximum TDN at the milk stage (trial 2; 708 g TDN kg^{-1} DM). On average, TDN changed by 3 g kg^{-1} DM among growth stages. The TDN range in the current study is similar to BMR forage sorghum variety trials conducted in Texas (soft dough harvest), ranging from 563 to 713 g TDN kg^{-1} DM (Miller and Stroup, 2003).

Optimum timing of harvest for forage nutritive value is dependent on the specific quality parameter that is most desired. Early harvest resulted in greater fiber digestibility and CP concentrations, while harvest at soft dough resulted in greater starch, DM, and NFC concentrations. To optimize yield and allow for timely planting of a winter cereal, harvest at the flower or milk stage is recommended, recognizing that the lower DM content at these stages compared to soft dough requires management practices to facilitate proper silage fermentation. Reduced starch concentrations at the flower or milk stages can be addressed through diet adjustments.

Harvest Timing, Dietary Inclusion, and ME and MP Predictions

Studies on the impact of forage sorghum growth stage at harvest on milk performance in dairy cows are scant. A feeding trial replacing BMR forage sorghum with corn silage in Nebraska concluded that cows fed diets with BMR forage sorghum (BMR-6) resulted in similar milk production (34.1 kg d^{-1}) to those cows fed diets with corn silage (33.8 kg d^{-1}) (Oliver et al., 2004). Another study in Pennsylvania found that diets that included forage sorghum had less DM intake (DMI) (26.0 kg d^{-1}) and milk yield (38.7 kg d^{-1}), and similar energy-corrected milk yield (35.1 kg d^{-1}) compared to a corn silage-only diet (26.7 kg DMI d^{-1}, 39.6 kg milk d^{-1}, and 36.9 kg energy-corrected milk d^{-1}), although the differences were small (Harper et al., 2017). Sorghum in these studies was harvested at a single growth stage (hard dough in Oliver et al., 2004; milk in Harper et al., 2017), so comparisons among growth stages at harvest cannot be made based on these studies.

In our study, the impact of substitution of corn silage by forage sorghum on milk yield predictions varied depending on the growth stage at which sorghum was harvested. For 5 trials (trials 1, 3, 4, 6, and 7), there was an interaction between growth stage and percent sorghum substitution on ME allowable milk (Table 6.9, Figure 6.2). For trials 1, 4, and 6, inclusion of sorghum forage harvested at boot, flower, and milk stages resulted in less ME allowable milk as the percent substitution in the TMR increased, while with harvest at the soft dough stage, the impact of substitution on ME was consistent. For trials 3 and 7, the soft dough and milk harvests remained fairly stable in ME allowable milk while the boot and flower harvests decreased with increasing sorghum addition to the ration. For trial 2, ME allowable milk was impacted by main effects of both growth stage and percent substitution; the milk and soft dough stages had greater ME allowable milk than the boot and flower stages across substitutions, and greater sorghum substitution resulted in lower ME allowable milk across growth stages. For trial 5, substitution of forage sorghum for corn silage resulted in decreased ME allowable milk independent of the growth stage at which the sorghum was harvested.

Table 6.9. Predicted metabolizable energy (ME) allowable milk as impacted by forage sorghum growth stage at harvest and percent substitution for corn silage in a typical dairy TMR.

Trial	Sub.[†]	Boot	Flower	Milk	Soft Dough	Growth stage	Percent substitution	Interaction
	%	Predicted ME allowable milk (kg)				------------------- P	----------------------	
All	0	41.9	41.9	41.9	41.9			
1	25	41.1	41.0	41.2	41.5	< 0.0001	< 0.0001	0.0001
	50	40.3	40.1	40.4	41.0			
	75	39.4	39.2	39.6	40.5			
	100	38.6	38.3	38.9	40.1			
2	25	41.5	41.6	41.8	41.9	< 0.0001	0.0018	0.2161
	50	41.1	41.3	41.8	41.9			
	75	40.7	41.0	41.7	41.9			
	100	40.3	40.7	41.6	41.9			
3	25	41.2	41.6	N/A	41.9	< 0.0001	< 0.0001	0.0044
	50	40.6	41.2	N/A	41.9			
	75	39.9	40.9	N/A	41.9			
	100	39.2	40.5	N/A	41.8			
4	25	41.4	41.5	41.5	41.7	< 0.0001	< 0.0001	0.0124
	50	40.8	41.1	41.0	41.6			
	75	40.2	40.7	40.6	41.5			
	100	39.7	40.3	40.2	41.3			
5	25	41.2	41.4	41.3	41.2	0.0013	< 0.0001	0.6639
	50	40.5	40.8	40.7	40.6			
	75	39.9	40.2	40.1	39.9			
	100	39.2	39.7	39.5	39.2			
6	25	41.4	41.5	41.6	41.9	< 0.0001	< 0.0001	< 0.0001
	50	40.8	41.0	41.4	41.9			
	75	40.3	40.5	41.2	41.9			
	100	39.7	40.1	40.9	41.9			

Table 6.9 (Continued)

Trial	Sub. †	Boot	Flower	Milk	Soft Dough	Growth stage	Percent substitution	Interaction
	%	Predicted ME allowable milk (kg)				------------------- *P*	----------------------	
7	25	41.3	41.6	41.7	41.7	< 0.0001	< 0.0001	< 0.0001
	50	40.8	41.3	41.5	41.5			
	75	40.2	41.1	41.2	41.3			
	100	39.6	40.8	41.0	41.1			

†Percent forage sorghum substitution for corn silage.

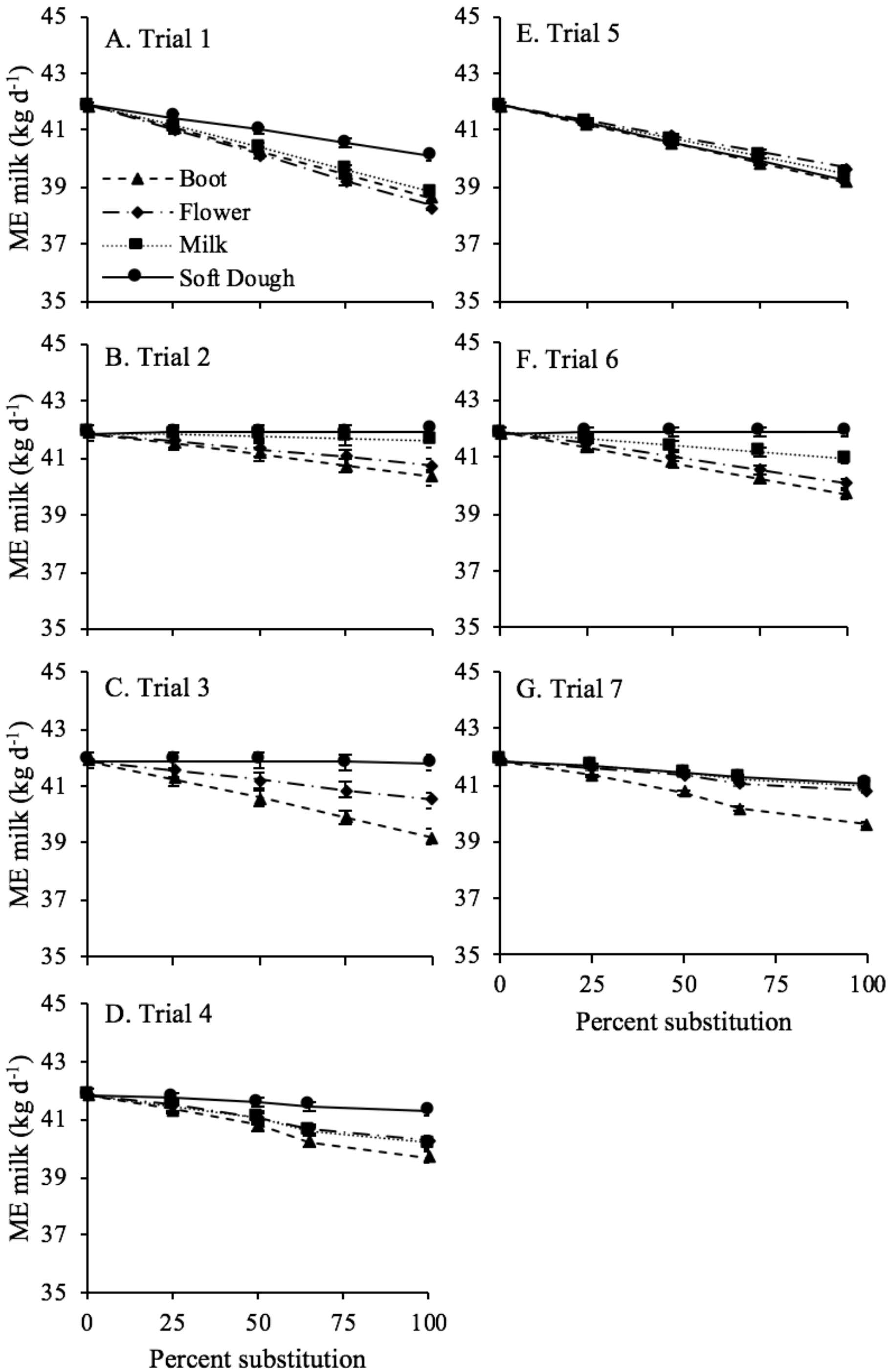

Figure 6.2. Metabolizable energy (ME) allowable milk for seven brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Harvest took place at four growth stages. Sorghum was substituted for different percentages of corn silage in a typical dairy total mixed ration. There was a significant interaction ($P \leq 0.05$) between growth stage and percent substitution for all trials except for Cayuga 2015 (B) and Tompkins 2014 (E). Error bars represent 1 SE.

On average across trials, predicted ME allowable milk decreased from 41.9 kg d^{-1} (corn silage only) to 39.5, 40.1, 40.3, and 41.1 kg d^{-1} (sorghum only) for the boot, flower, milk, and soft dough growth stages, respectively. Although the aNDFom content of the forage sorghum was significantly higher than the aNDFom content of the corn silage, a couple of conditions must be recognized. First, the corn silage without the dilution of starch would be approximately 70 to 74% aNDFom because the plant is a grass at full maturity, so when evaluating the fiber components, the corn silage fiber is much more mature than the sorghum forage. This level of maturity leads to greater indigestibility primarily through increased lignification and cross-linking between the lignin and carbohydrates in the hemicellulose (Raffrenato et al., 2017). The forage sorghum is a BMR with lower lignin and lower capacity to cross-link, and it was grown in cooler weather conditions, thus the $NDFD_{30}$ is higher despite the apparent higher aNDFom content which would allow for similar milk yield between the forages due to the higher sorghum digestibility.

The predicted MP allowable milk results were more variable among trials than the ME allowable milk results. For 3 trials there was an interaction between growth stage at harvest and percent sorghum substitution (trials 1, 4, and 7; Table 6.10, Figure 6.3).

Table 6.10. Predicted metabolizable protein (MP) allowable milk as impacted by forage sorghum growth stage at harvest and percent substitution for corn silage in a typical dairy TMR.

Trial	Sub.[†]	Boot	Flower	Milk	Soft Dough	Growth stage	Percent substitution	Interaction
	%	Predicted MP allowable milk (kg)				-------------------- P -------------------		
All	0	43.0	43.0	43.0	43.0			
1	25	42.4	42.2	42.3	42.7	< 0.0001	< 0.0001	0.0337
	50	41.8	41.4	41.6	42.4			
	75	41.3	40.6	40.8	42.0			
	100	40.7	39.9	40.1	41.7			
2	25	43.1	43.1	43.2	43.3	0.2342	0.3400	0.9987
	50	43.1	43.2	43.3	43.6			
	75	43.1	43.3	43.4	43.9			
	100	43.2	43.4	43.5	44.2			
3	25	43.0	43.4	N/A	43.3	0.0053	0.1035	0.6719
	50	42.9	43.7	N/A	43.6			
	75	42.9	44.0	N/A	43.8			
	100	42.9	44.4	N/A	44.1			
4	25	42.8	42.8	42.8	43.2	< 0.0001	0.0007	0.0265
	50	42.5	42.5	42/5	43.3			
	75	42.3	42.3	42.3	43.4			
	100	42.0	42.0	42.0	43.6			
5	25	42.4	42.6	42.6	42.5	0.0046	< 0.0001	0.7985
	50	41.8	42.2	42.1	42.0			
	75	41.2	41.7	41.7	41.5			
	100	40.6	41.3	41.2	41.0			
6	25	43.1	43.3	43.3	43.6	< 0.0001	< 0.0001	0.0811
	50	43.3	43.5	43.5	44.2			
	75	43.4	43.8	43.7	44.8			
	100	43.6	44.0	43.9	45.4			

Table 6.10 (Continued)

Trial	Sub.[†]	Boot	Flower	Milk	Soft Dough	Growth stage	Percent substitution	Interaction
	%	Predicted MP allowable milk (kg)				-------------------- *P* -------------------		
7	25	42.8	43.2	43.2	43.1	< 0.0001	0.5969	0.0005
	50	42.6	43.3	43.3	43.2			
	75	42.4	43.5	43.4	43.2			
	100	42.3	43.6	43.5	43.3			

[†]Percent forage sorghum substitution for corn silage

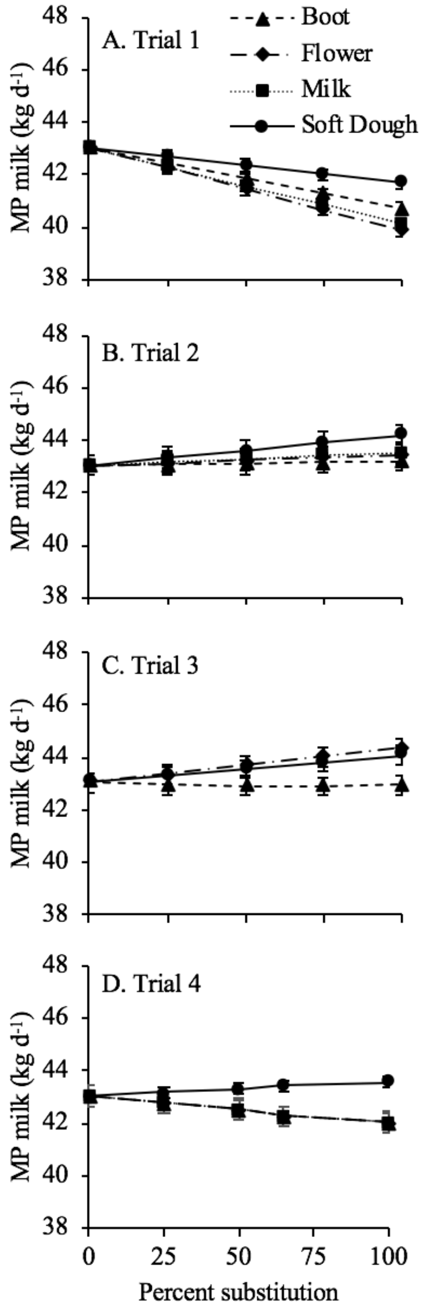

Figure 6.3. Metabolizable protein (MP) allowable milk for seven brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Harvest took place at four growth stages. Sorghum was substituted for different percentages of corn silage in a typical dairy total mixed ration. There was a significant interaction ($P \leq 0.05$) between growth stage and percent substitution for three trials: Cayuga 2014 (A), Cayuga 2017 (D), and Tompkins 2017 (G). Error bars represent 1 SE.

For trial 1, sorghum harvested at the boot, flower, milk, and soft dough stages had decreased predicted MP allowable milk with increased percent sorghum in the ration. The predicted MP allowable milk decreased the least with increasing sorghum substitution when sorghum was harvested at the soft dough stage, followed by greater decreases with substitutions when forage harvested at the flower, milk, or boot stages was used. This was likely due to less starch in the diet for microbial growth. When the forage sorghum was harvested at the soft dough stage in trial 4, the diet resulted in increased MP allowable milk with greater sorghum substitutions in the diet, while diets with forage sorghum harvested at the boot, flower, and milk growth stages had decreased predicted MP allowable milk. For trial 7, forage sorghum harvested at the flower, milk, and soft dough growth stages led to an increase in predicted MP allowable milk with increasing substitution for corn silage, while forage sorghum harvested at the boot stage resulted in a decrease in predicted MP allowable milk with increasing substitution. There were no differences in MP allowable milk among forage sorghum growth stages at harvest or percent substitutions for corn silage in trial 2. There was a main effect of sorghum growth stage at harvest on predicted MP allowable milk for trial 3, where the boot stage had lower predicted MP allowable milk than the flower, milk, or soft dough stages. Trials 5 and 6 had main effects of both percent sorghum substitution and growth stage at harvest on predicted MP allowable milk. For trial 5, MP allowable milk decreased with increased sorghum substitution in the diet; the boot stage had the greatest predicted MP allowable milk decrease followed by the soft dough, milk, and flower growth stages. For trial 6, MP allowable milk increased with greater sorghum substitution in the diet, with soft dough increasing the most followed by the flower, milk, and boot growth stages. Across all trials, MP allowable milk was 43 kg d^{-1} with only corn silage in the diet, and 42, 43, 42, and 43 kg d^{-1} for boot, flower, milk, and soft dough with only sorghum in the diet. Based on these results, if forage sorghum harvested at the flower or milk growth stage is to be substituted for corn silage in a dairy TMR, protein might be sufficient but additional energy supplementation will be needed to promote microbial growth to support the amino acid requirements of the cow.

CONCLUSIONS

Brachytic dwarf BMR forage sorghum is a potential alternative to corn silage in double cropping rotations with winter cereals grown for forage in New York. Forage sorghum can be harvested as early as the flower stage without impacting total DM yield. Harvest prior to the soft dough stage results in increased $NDFD_{30}$, aNDFom, ADF, and CP concentrations, and decreased NFC, starch, and DM concentrations of the harvested forage. Direct substitution of corn silage with sorghum silage in a dairy TMR is possible based on model simulations. However, energy supplements are needed if sorghum is harvested before the soft dough stage, primarily due to lower starch concentrations of sorghum harvested at or before the soft-dough growth stage, compared to corn silage harvested after physiological maturity. Additional forage in the diet may also be necessary if including sorghum in a TMR due to changes in fiber digestibility among growth stages at harvest. Adjustments in chop length and additives may be necessary to ensure proper ensiling of direct-chopped forage at flower, milk, and soft dough stage, due to the increased moisture content of the forage at harvest, compared to corn silage. Future work assessing milk performance in feeding trials, the economics of growing, processing, and feeding of forage sorghum, and how to best handle the low DM content of early harvested forage sorghum in the northeast United States is needed.

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CHAPTER 7: DOUBLE-CROPPING WITH FORAGE SORGHUM AND TRITICALE IN NEW YORK

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ABSTRACT

Forage double-cropping can be a productive practice in New York. A rotation trial with forage triticale (x *Triticosecale* Wittmack) and forage sorghum [*Sorghum bicolor* (L.) Moench] was conducted in central New York from 2016 to 2018. Treatments included four timings of sorghum harvest followed by next-day triticale planting, five triticale spring N rates (0, 34, 67, 101, 135 kg N ha^{-1}), and two N treatments applied at sorghum planting (fertilized and unfertilized) using a randomized complete block split-split-plot design in four replications. The most economic rate of N (MERN) for triticale in spring 2016 was 86 kg N ha^{-1} with a yield at the MERN of 4.0 Mg dry matter (DM) ha^{-1}. In fall 2016 and spring 2017, total forage yield (triticale plus sorghum) did not increase after the mid-September harvest for the +N and 135 kg spring N ha^{-1} plots (23.8 Mg DM ha^{-1} average). In fall 2017 and spring 2018, there was no difference in total forage yield across harvest timings (13.4 Mg DM ha^{-1}

average) likely due to less growing degree days (GDD) that year. We recommend harvesting sorghum ~1150 GDD after planting, or at the soft-dough stage. Earlier harvests resulted in lower yield but greater digestibility and crude protein. Spring-applied N did not impact forage sorghum performance but resulted in MERNs of 0 kg N ha^{-1} for the triticale that followed. Fertilizing sorghum according to N needs and timely harvest can support both sorghum and triticale yields without having to fertilize triticale in the spring.

INTRODUCTION

Forage production is an important component of dairy farming in New York, as many producers grow the majority of their feed on-farm. The most common forages grown in New York are corn silage (*Zea mays* L.) (3 to 4 yr) followed by an alfalfa (*Medicago sativa* L.)/grass mix (3 to 4 yr). During the corn silage years, the ground is often left bare over the winter months due to relatively short growing seasons in this region. However, planting cover crops following corn silage harvest has become a more common practice in recent years, reducing the risk of soil erosion otherwise associated with bare ground as well as aiding in nutrient recycling and soil fertility management (Long et al., 2013; Ketterings et al., 2015b; Lyons et al., 2017). Harvesting winter-hardy cover crops for forage in the spring, defined here as double-cropping, can provide an additional benefit of spring yield (Ketterings et al., 2015a; Lyons et al., 2019c). While there are many potential benefits to forage double-cropping in New York, increased labor and storage needs, extremely wet or dry conditions in spring or fall, and overlap with the corn silage growing season are potential challenges that need to be considered and managed. In New York, forage winter cereal harvest (at the flag-leaf stage) typically takes place in mid- to late-May which could delay planting of the next crop until late-May or early-June. Forage sorghum is a potential warm-season crop that could fit a forage double-cropping rotation with winter cereals better than corn silage. Sorghum requires warmer soil temperatures than corn silage (16°C minimum; Peacock and Heinrich, 1984), which typically occurs in early June in New York (Lyons et al., 2019b). Forage sorghum is comparable to corn silage in both yield and nutritive value (Grant et al., 1995; Aydin et al., 1999; Oliver et al., 2004; Marsalis et al., 2010), except for starch concentrations which tend to be lower in forage sorghum (Oliver et al., 2004). Forage sorghum can also potentially be harvested earlier in the fall than corn silage without losing yield (Lyons et al., 2019a), which allows for more timely winter cereal planting.

Previous work with forage winter cereals in New York, including triticale, cereal rye (*Secale cereale* L.) and winter wheat (*Triticum aestivum* L.), has found that timing of fall planting and spring N fertilization are important management practices for optimum yield and forage nutritive value (Lyons et al., 2017; Lyons et al., 2018a; Lyons et al., 2019c). A New York study found that earlier planted triticale (before 20 September) generated more fall biomass and was better able to utilize fall available soil N, suggesting that leftover nutrients from the previous crop or fall manure applications could be scavenged by winter cereals if they are planted early enough (Lyons et al., 2017). A similar study in Virginia showed that early planting was essential for winter rye to effectively utilize residual fertilizer N following corn (Ditsch et al., 1993). While planting date was important for fall N scavenging, the subsequent study by Lyons et al. (2018a) determined that earlier planted triticale (before 20 September) yielded more than triticale planted later, but spring N needs were not impacted by planting date or fall N availability. A statewide study with on-farm trials across New York reported that forage winter cereals can have yields at the MERN ranging from 1.0 to 6.9 Mg DM ha^{-1} with MERNs from 0 to > 135 kg N ha^{-1} (Lyons et al., 2019c). The winter cereals that yielded < 2.2 Mg DM ha^{-1} were typically planted late in the fall on fields lacking sufficient soil drainage and recent manure histories. Lyons et al. (2019c) recommended that winter cereals grown for forage on fields with well-drained soils, with recent manure histories, and where planting occurred before 1 October may not need additional N, while for all other situations ~19 kg N ha^{-1} per Mg DM ha^{-1} was needed. However, the impact of N management of the main summer crop (corn silage or forage sorghum) on N needs of forage winter cereals in New York needs additional research.

Although there is no published evidence of forage winter cereals impacting corn silage performance in a double-cropped rotation in New York, a study by Krueger et al. (2012) in Minnesota observed that a rotation with corn silage and rye resulted in reduced total forage DM yield in 2 of 3 yr and reduced DM corn yield by 15 to 25%. In the double-cropped rotation in Krueger et al. (2012), corn planting was delayed to mid-May to early June as compared to an early to mid-May planting in a corn silage monocrop system, which likely impacted the corn yield. In contrast, the study by Heggenstaller et al. (2008) in Iowa reported that a double-cropped corn/triticale rotation had greater total season yield than mono-cropped corn (22.7 vs 18.2 Mg DM ha^{-1}, respectively), even with a delayed corn planting from late

April/early May to early/mid-June. Regardless of the impact of double-cropping on the warm-season crop, using an alternative forage crop with a later planting date, such as sorghum or a shorter season corn, could allow for greater full-season yields that would be obtained with a mono-cropped summer annual alone.

Krueger et al. (2012) observed that soil nitrate concentrations did not accumulate over the course of the double-crop rotation but did accumulate in the monocrop rotation which could impact N needs of corn following a forage winter cereal. Heggenstaller et al. (2008) also suggested that because more nutrients are removed in a double-cropped system, increased fertilization may be needed to sustain the rotation. A study with forage winter cereals in New York observed that soil nitrate at winter cereal harvest (flag-leaf stage in mid- to late May) was less when the forage winter cereals had greater yields (1.7 mg NO_3-N ha^{-1} with 6.9 Mg DM ha^{-1} yield) compared to those with lower yields (16.7 mg NO_3-N ha^{-1} with 2.2 Mg DM ha^{-1} yield) (Lyons et al., 2019c), suggesting that more N may be needed for the crop that follows high-yielding winter cereals. Research on the impact of double-cropping with forage winter cereals on N needs of the main crop and vice versa is needed.

Objectives of this study were to evaluate: 1) forage triticale N needs, 2) impact of sorghum timing of harvest on full season yield and forage nutritive value, and 3) impact of carryover N on forage sorghum and forage triticale performance.

MATERIALS AND METHODS

Location and Experimental Design

A rotation study with forage sorghum and forage triticale was conducted at the

Musgrave Research Farm in Aurora, New York, from October 2015 to June 2018 (42.73 N, -76.66 W). This study used an annual forage double-cropping rotation cycle that was initiated with planting of triticale in mid-October 2015 (all one planting date) followed by N application at multiple rates at dormancy break in April 2016, harvest at flag-leaf in May 2016 (all plots), sorghum planting in June, and sorghum harvest at one of four biweekly timings in the fall. Triticale was then planted the day after sorghum harvest and harvested at flag-leaf each spring.

The experimental design was a randomized complete split-split plot design with four replications. The main plots (0.1 ha each) were four timings of sorghum harvest followed by next-day triticale planting (Table 7.1). Split-plots (0.02 ha each) were five N rates (0, 34, 67, 101, and 135 kg N ha^{-1}) applied at triticale dormancy break in early spring. Split-split plots (0.01 ha each) were two N rates, unfertilized (-N) and fertilized (224 kg N ha^{-1}; +N), applied at sorghum planting in June. The -N plots assessed the possible N carryover from the triticale spring-applied N to the sorghum, and the +N plots were measured to estimate maximum sorghum yield without N limitations. Nitrogen was broadcasted in the form of Agrotain ultra-treated urea (Koch Agronomic Services, LLC, Wichita, KS).

Table 7.1. Experimental timeline for a double-cropping rotation study with forage sorghum and forage triticale in central New York from 2015 to 2018. Soil sampling consisted of eight cores (0-20 cm) per plot. All plots underwent primary and secondary tillage before all plantings. Both crops were planted with a conventional drill. All biomass above 10 cm from the ground was removed from plots at harvest.

Crop	Activity	2015-2016	2016-2017	2017-2018
Triticale	Planting and soil sampling	10/16/2015	9/2/2016 9/16/2016 10/7/2016 10/14/2016	9/13/2017 9/21/2017 10/4/2017 10/20/2017
	Fall biomass	na†	11/15/2016	11/14/2017
	Soil sampling	4/15/2016	4/12/2017	4/23/2018
	Fertilization	4/18/2016	4/14/2017	4/24/2018
	Harvest	5/26/2016	5/18/2017	5/24/2018
Sorghum	Planting	6/3/2016	6/13/2017	na†
	Soil sampling	6/3/2016	6/12/2017	na†
	Fertilization	6/3/2016	6/13/2017	na†
	Harvest	9/1/2016 9/15/2016 10/6/2016 10/12/2016	9/12/2017 9/20/2017 10/3/2017 10/19/2017	na†

†na, not applicable. Fall biomass was not collected in 2015, and the study was completed in June 2018.

There were two primary soil types within the plot area. Fields 1 and 3 included a Lima silt loam (fine-loamy, mixed, semiactive, mesic Oxyaquic Hapludalfs) with 0 to 3% slopes. Fields 2, 3, and 4 had a mix of Kendaia (fine-loamy, mixed, semiactive, nonacid, mesic Aeric Endoaquepts) and Lyons (fine-loamy, mixed, active, nonacid, mesic Mollic Endoaquepts) soils, with 0 to 3% slopes. Both soil types classified as soil management group (SMG) 2 (Ketterings et al., 2003). The most recent manure addition to these fields was in 2009 so the field did not have a recent manure history.

Weather data were collected from an on-site weather station (Table 2). There was more precipitation than normal in October 2016 and April, May, July, and October 2017, and less precipitation than normal in November 2015, June and July 2016, and August and December 2017. Average monthly temperatures were approximately normal.

Table 7.2. Monthly precipitation and temperatures for a double-cropping rotation study with forage sorghum and forage triticale in central New York from 2015 to 2018. Weather data were obtained from an on-site weather station. Average monthly temperatures were determined from calculated daily averages: [(maximum daily temperature – minimum daily temperature)/2].

	2015-2016	2016-2017	2017-2018	30 yr average
Total monthly precipitation	----------	---------- cm	----------	----------
October	7.2	20.1	15.2	8.1
November	3.3	4.9	6.3	8.5
December	7.9	6.1	3.3	6.2
January	2.5	5.1	8.0	4.9
February	9.1	4.2	4.0	4.9
March	4.8	7.6	8.2	6.4
April	4.7	15.6	7.2	8.3
May	5.1	13.3	5.2	8.1
June	1.9	9.7	4.1	10.4
July	4.8	18.6	na†	8.4
August	11.6	3.7	na†	9.2
September	5.5	6.5	na†	10.7
Average monthly temperature	----------	---------- °C	----------	----------
October	9.9	11.5	13.8	10.5
November	7.2	5.9	3.3	4.7
December	4.8	-1.5	-3.3	-1.3
January	-3.7	-0.6	-6.1	-4.6
February	-2.4	1.6	-0.3	-3.8
March	3.7	-0.8	-1.1	1.0
April	4.9	9.9	3.8	7.4
May	13.6	12.9	16.7	14.2
June	18.6	18.7	18.9	19.3
July	22.1	20.8	na†	21.8
August	22.8	19.5	na†	20.9
September	18.2	17.3	na†	16.7

†na, not applicable. Study was completed in June 2018.

Planting and Harvest

Forage triticale (Trical 815, King's Agriseeds Inc., Ronks, PA) was drilled at a 2.54 cm depth at 135 kg seeds ha^{-1} with 19.5 cm row spacing for all planting dates (Table 7.1). Triticale was harvested with a Carter Harvester (Carter Mfg. Co., Inc., Brookston, IN) at the flag-leaf stage (Feekes stage 7; Zadoks et al., 1974*)* in May at 10 cm above the soil surface through the center of the plots in a 0.9 m strip. Subsamples from each plot for DM and nutritive value determination were clipped using electric clippers at 10 cm above the soil surface, placed in brown paper bags, and weighed in the field.

A brachytic dwarf brown midrib (BMR) forage sorghum cultivar (AF7102, Alta Seeds, Irving, TX) adapted to the northeastern United States was drilled at ~3 cm planting depth using 17 kg seed ha^{-1} with 38 cm row spacing on 3 June in 2016 and 13 June in 2017. Approximately bi-weekly, sorghum was hand-harvested in one, 1.5 m by 4 row area per plot and weighed in the field. Random subsamples of ~8-10 stalks were coarsely ground using a leaf shredder-chipper (MacKissic Inc., Parker Ford, PA) in the field. Chopped sorghum was thoroughly mixed, subsampled, placed in sealed plastic bags, and put on ice in a cooler for transportation back to the laboratory.

Growing degree days were calculated by subtracting the lower threshold temperature for sorghum (10°C) or triticale (0°C) from the average daily temperature (°C): [($Temperature_{max}$ – $Temperature_{min}$)/2 (Gallagher, 1979; Gerik et al., 2003). Daily temperatures included the day of planting through the day prior to harvest.

Soil and Forage Analysis

Prior to all fertilizer applications, eight soil cores (0-20 cm depth) were taken in each plot. Subsamples were composited by replication and submitted for basic fertility analysis (Analytical Laboratory and Maine Soil Testing Service, Orono, ME; Table 7.3). Soil pH was measured in a 1:1 (w/v) water extract, and soil organic matter (SOM) was determined by loss-on-ignition through exposure to 500°C for two hours (Storer, 1984). The Cornell Morgan soil test was used to extract P, K, Mg, Ca, Mn, and Zn by shaking dried samples in a 1:5 (v/v) ratio for 15 min in Morgan solution (1 M sodium acetate buffered at pH 4.8; Morgan, 1941). The extracts were filtered through a Whatman No. 2 equivalent filter paper following procedures outlined in NEC-1012 (Northeast Coordinating Committee for Soil Testing, 2011). Filtered extracts were analyzed for K, Mg, Ca, Mn and Zn using an inductively coupled plasma atomic emission spectrometer (ICP-AES, JY70 Type II, Jobin Yvon, Edison, NJ). Phosphorus was determined colorimetrically using the ammonium molybdate-ascorbic acid method (Knudsen and Beegle, 1988) with a Lachat QuikChem® 8000 flow injection analyzer (Lachat Instruments, Milwaukee, WI).

Table 7.3. Soil pH, organic matter, P, K, and Mg throughout a double-cropped rotation with forage sorghum and forage triticale in central New York from 2015 to 2018. Soil measurements began in 2016. Values are averages of 16 soil composites, each containing 80 cores (0-20 cm depth).

Year	Timing†	pH	SOM‡	Morgan-P§	Morgan-K§	Morgan-Mg§
			$g\ kg^{-1}$	------------------mg kg^{-1} soil	----------------------	
2016	Spring	7.7	3.2	9.5 (H)	56 (H)	351 (VH)
	Summer	7.6	3.0	7.0 (H)	43 (M)	358 (VH)
2017	Spring	7.8	3.0	7.0 (H)	48 (M)	362 (VH)
	Summer	7.8	3.1	6.5 (H)	44 (M)	364 (VH)
2018	Spring	7.8	2.8	7.0 (H)	48 (M)	372 (VH)
	Summer	7.8	3.0	7.0 (H)	40 (M)	354 (VH)

†Soil samples were taken at triticale green-up (spring) and sorghum planting (summer).
‡Soil organic matter (SOM) determined by loss on ignition (Storer, 1984).
§Morgan extraction (Morgan, 1941); L = low, M = medium, H = high, and VH = very high according to Cornell Cooperative Extension (2018).

Soil samples were also submitted to the Nutrient Management Spear Program Laboratory. Soil samples at dormancy break were analyzed for 2 M KCl extractable NO_3-N and NH_4-N (Keeny and Nelson, 1982) with a discrete analyzer (EasyChem Plus, Chinchilla Scientific, Oak Brook, IL) and soil samples at both triticale and sorghum planting were analyzed for Morgan extractable NO_3-N (Morgan, 1941).

All forage samples were dried at 55°C and ground to pass through a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ). Samples were analyzed for fiber content and digestibility by the Cherney laboratory at Cornell University (Ithaca, NY). Neutral detergent fiber (NDF) was analyzed according to Van Soest et al. (1991) including sodium-sulfite using the ANKOM system (ANKOM Technology, Fairport, NY). In vitro 30 h fiber digestibility ($NDFD_{30}$) for sorghum and 48 h ($NDFD_{48}$) for triticale was determined according to ANKOM procedures described by Valentine et al. (2018) using the Daisy II$^{200/220}$ incubator (ANKOM Technology, Fairport, NY). Ruminal fluid inoculum was collected from a non-lactating, rumen-fistulated Holstein cow (*Bos taurus*) fed a medium quality hay diet ad libitum. Samples were incubated in F57 ANKOM digestion bags for 30 h (sorghum) and 48 h (triticale) at 39°C. Undigested residues were extracted with neutral detergent solution. Forage samples were also submitted to Brookside Laboratories, Inc. (New Bremen, OH.) for total forage C and N content determined by combustion analysis using an element analyzer (Vario El Cube, Elementar, Germany). Total forage N was multiplied by 6.25 to determine crude protein (CP) concentration following Method 46-10.01 of AACC (AACC International, 1999).

Statistical Analysis

There was a significant effect of year on both sorghum and triticale performance. Because of this, years were analyzed individually using PROC MIXED of SAS v. 9.4 with the Tukey adjustment for multiple comparisons (SAS Institute, 1999). Outliers were identified with Cooks distance (0.05 threshold), the INFLUENCE option in PROC REG, and extreme observations using PROC UNIVARIATE. Values identified by two or more of these tests were removed from the dataset.

Triticale MERNs were determined using a quadratic plateau model:

$$Yield\ plateau\ (kg\ N\ ha^{-1}) = \frac{-b}{2c} \quad [1]$$

and the MERN:

$$MERN\ (kg\ N\ ha^{-1}) = \frac{N\ cost - b \times crop\ value}{2c \times crop\ value} \quad [2]$$

where *b* is the linear coefficient, *c* is the quadratic coefficient, N cost is \$1.54 kg^{-1}, and crop value is \$275.00 Mg^{-1} DM (Lyons et al., 2018b). The linear and quadratic coefficients were determined using PROC REG of SAS (SAS Institute, 1999).

RESULTS AND DISCUSSION

Initial triticale MERN and Yield

In spring 2016, triticale responded to N addition at dormancy break (P = 0.0011) with yields of 3.0, 4.2, 4.9, 4.9, and 5.0 for the 0, 34, 67, 101, and 135 kg N ha^{-1} treatments, respectively. The MERN was 86 kg N ha^{-1} with a yield at the MERN of 4.0 Mg DM ha^{-1}. As the triticale had been planted in mid-October of 2015 (one planting date for all plots), the spring 2016 MERN was considered a baseline MERN for the triticale in the rotation. This 2016 spring MERN and yield at the MERN were similar to those reported in other New York trials. For example, in the study by Lyons et al. (2018a), triticale planted between 10 September and 2 October (no fall fertilization or recent manure history) had MERNs ranging from 80 to 110 kg N ha^{-1}, averaging 93 kg N ha^{-1}, with yields at the MERN ranging from 1.9 to 5.8 Mg DM ha^{-1}, averaging 4.0 Mg DM ha^{-1}. Another study by Lyons et al. (2019c) observed that eight sites with no manure history planted between 10 September and 12 October either had MERNs of 0 (two sites) or MERNs ranging from 68 to 112 kg N ha^{-1} (90 kg N ha^{-1} average), with yields at the MERN ranging from 3.2 to 5.4 Mg DM ha^{-1}, averaging 4.6 Mg DM ha^{-1}.

Sorghum Timing of Harvest, Total Season Yield, and Forage Nutritive Value

While the -N treatment was necessary to evaluate possible carryover effects of the rotation, N application at planting was necessary for both sorghum yield and nutritive value. Across all harvest timings, -N sorghum averaged 13.5 and 6.8 Mg DM ha^{-1} compared to 19.6 and 12.6 Mg DM ha^{-1} for +N sorghum in 2016 and 2017, respectively. Crude protein was also dependent on fertilization at sorghum planting. The -N plots averaged 78 and 56 g kg^{-1} CP while the +N plots averaged 97 and 80 g kg^{-1} CP in 2016 and 2017, respectively. Other quality parameters are not typically impacted by N fertilization rate (Lyons et al., 2019b). Although the MERN was not calculated for this field, a sorghum N-rate study conducted in New York with the same sorghum variety showed MERNs ranging from 150 to 262 kg N ha^{-1} (203 kg N ha^{-1} average) for non-manured sites (Lyons et al., 2019b). Based on these findings, the 224 kg N ha^{-1} rate used for the +N plots in the current study was likely adequate for sorghum performance.

For the plots that had received the most N and were non-N limiting (+N for sorghum, 135 kg N ha^{-1} at spring dormancy break for triticale), total season yield (fall 2016 sorghum harvest plus spring 2017 triticale yield) was maximized with the second harvest/planting in mid-September, when the sorghum was at the late flower to early milk stage (20.6 and 3.9 Mg DM ha^{-1} for sorghum and triticale, respectively; Figure 7.1). The second, third, and fourth harvest/planting times were not different in total season yield (24.5, 23.5, and 23.4 Mg DM ha^{-1} total yield, respectively), while the first harvest/planting time resulted in lower full-season yield (15.2 Mg DM ha^{-1} total yield). In the second year of the study (fall 2017 sorghum harvest plus spring 2018 triticale yield), there were no differences in total season yield among harvest/planting times (9.9, 14.6, 13.5, and 15.7 Mg DM ha^{-1} total season yield for the first, second, third, and fourth timings, respectively).

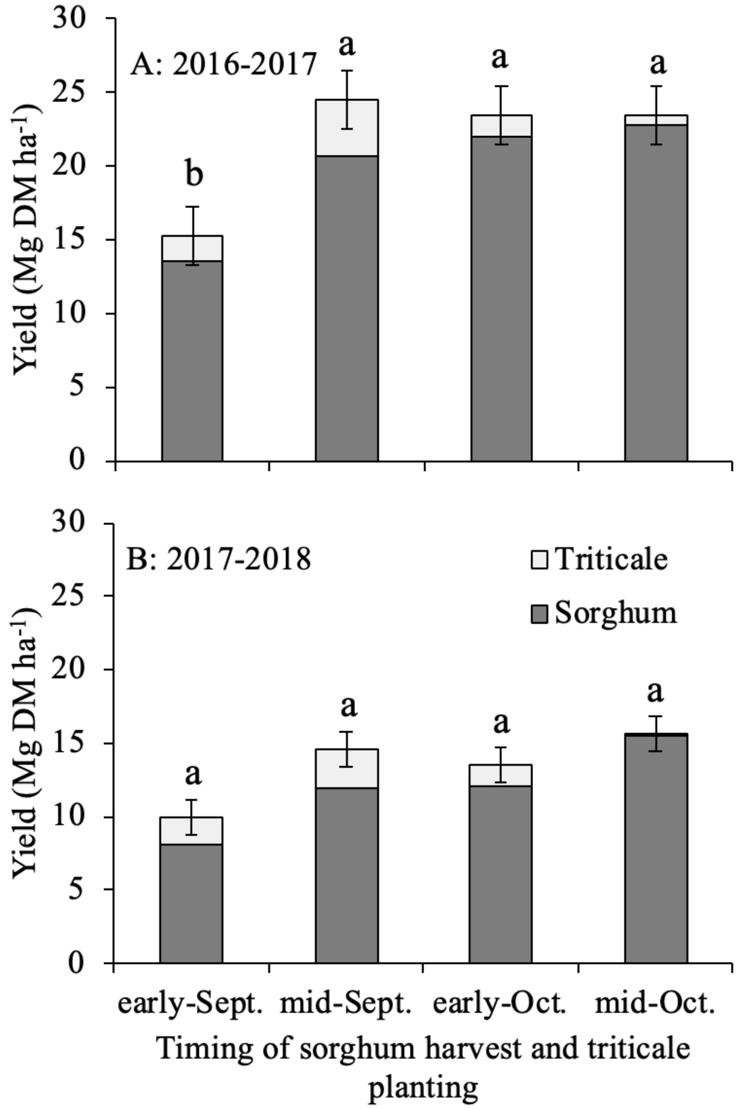

Figure 7.1. Total season yield for a double-crop rotation in New York with forage sorghum harvested in fall 2016 and forage triticale harvest in spring 2017 (A) and fall 2017 harvest of sorghum with spring 2018 triticale harvest (B) when N was non-limiting. Sorghum received 224 kg N ha^{-1} at planting, and triticale received 135 kg N ha^{-1} at dormancy break in the spring. Sorghum was harvested at four different timings in the fall followed by triticale planting. Error bars represent standard errors of the mean for total yield (sorghum and triticale). Different letters indicate significant differences ($P \leq 0.05$).

Fall 2017 sorghum yield was maximized at the late-milk to early-soft dough growth stage (15.5 Mg DM ha^{-1}), which occurred at the last harvest date in mid-October. However, triticale planted at the last planting date in fall 2017 yielded less than 0.2 Mg DM ha^{-1}. In spring 2018, the triticale yielded highest when planted mid-September in 2017 (2.6 Mg DM ha^{-1}), but sorghum harvested at that time yielded 3.5 Mg DM ha^{-1} less than the mid-October harvest (12 Mg DM ha^{-1}).

While this study did not compare the double-crop rotation to a monocrop rotation, monocrop forage corn and sorghum studies on nearby fields observed similar or lower total season yields compared with the current study. A sorghum trial reported yields at the MERN of 17.5 and 18.6 Mg DM ha^{-1} in 2016 and 2017, respectively (Lyons et al., 2019b). Corn trials on the same farm produced yields averaging 13.0 and 20.0 Mg DM ha^{-1} in 2016 and 2017, respectively (Lawrence et al., 2016; Lawrence et al., 2017). A study comparing double-cropping rotations in Iowa (corn/forage triticale and sorghum-sudangrass/forage triticale) with a corn monocrop rotation observed that both double-crop rotations produced more DM yield than the monocropped corn (Heggenstaller et al., 2008). The corn/forage triticale rotation yielded 22.7 Mg DM ha^{-1}, the sorghum-sudangrass/forage triticale yielded 23.0 Mg DM ha^{-1}, and the monocrop rotation yielded 18.2 Mg DM ha^{-1} (Heggenstaller et al., 2008).

Weather impacted crop performance between the two growing seasons. By mid-September in 2016, there were already more GDD than by the last harvest in mid-October 2017 (1151 vs 1129 GDD, respectively). The lesser GDD during the sorghum growing season in 2017 most likely contributed to the lower yields and delayed maturity as compared to 2016, as evidenced by a linear relationship between GDD and sorghum yield across the two years (Figure 7.2). Based on these results, in years with greater GDD, sorghum is likely to reach maximum yields earlier compared with growing seasons with less GDD, reflecting the adaptation of sorghum to warm, dry climates (Martin, 1930; Merrill et al., 2007). To manage for optimal sorghum yields in New York, it is recommended that harvest take place once ~1150 GDD (°C scale) have accumulated. If this does not occur by the soft dough growth stage, harvesting once the sorghum reaches soft dough is recommended.

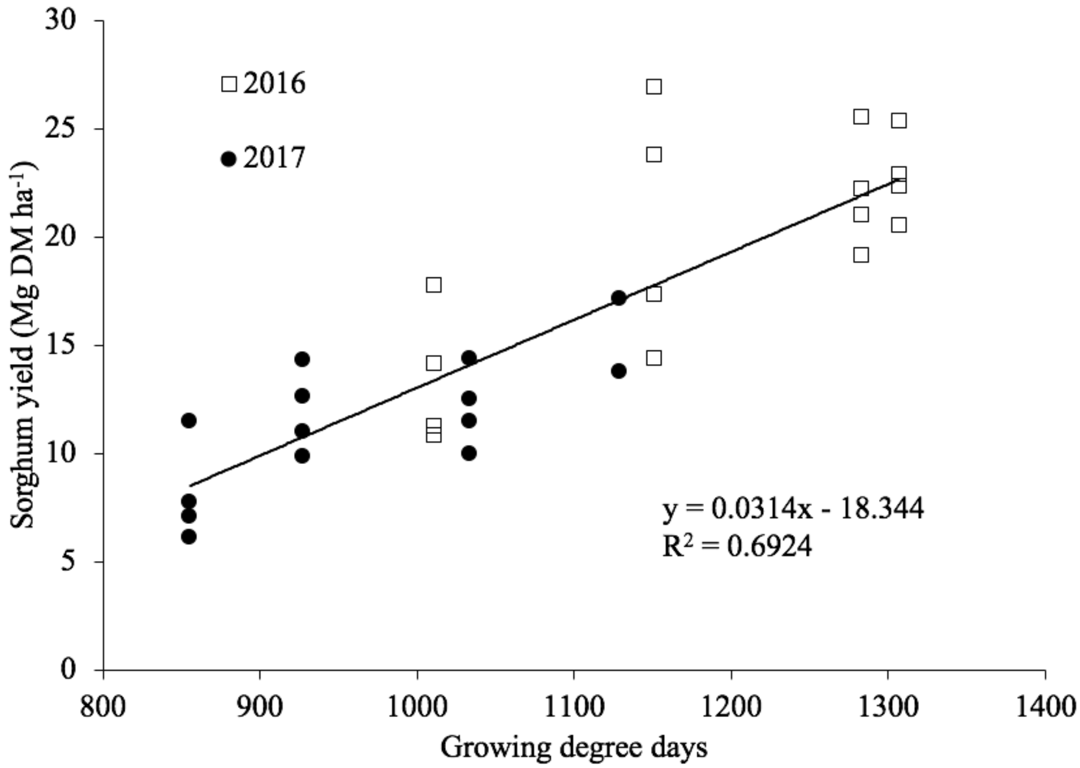

Figure 7.2. Forage sorghum yield and corresponding growing degree days (GDD) from 2016 to 2017 in central New York. Forage sorghum was harvested at four different times in the fall. Growing degree days were calculated by subtracting the lower threshold temperature for sorghum (10°C) from the average daily temperature (°C): [($Temperature_{max}$ – $Temperature_{min}$)/2.

Timing of sorghum harvest impacted DM, CP, in vitro true digestibility ($IVTD_{30}$), NDF, $NDFD_{30}$, acid detergent fiber (ADF), and acid detergent lignin (ADL) in both years. With later harvests, DM and ADL increased, while CP, $IVTD_{30}$, NDF, $NDFD_{30}$, and ADF decreased (Figure 7.3). From the first to the last harvest, sorghum (+N) increased from 186 to 286 g DM kg^{-1} and 29 to 33 g ADL kg^{-1} DM, respectively, and decreased from 127 to 81 g CP kg^{-1} DM, 794 to 783 g $IVTD_{30}$ kg^{-1} DM, 558 to 433 g NDF kg^{-1} DM, 632 to 498 g $NDFD_{30}$ kg^{-1} NDF, and 327 to 257 g ADF kg^{-1} DM, respectively. These results are similar to a sorghum timing of harvest study conducted on a nearby field (Lyons et al., 2019a). Although starch content was not measured, a similar study observed that starch increased by 16 g kg^{-1} DM from the boot to the flower stage, 47 g kg^{-1} DM from the flower to the milk stage, and 43 g kg^{-1} DM from the milk to the soft dough stage (Lyons et al. 2019a).

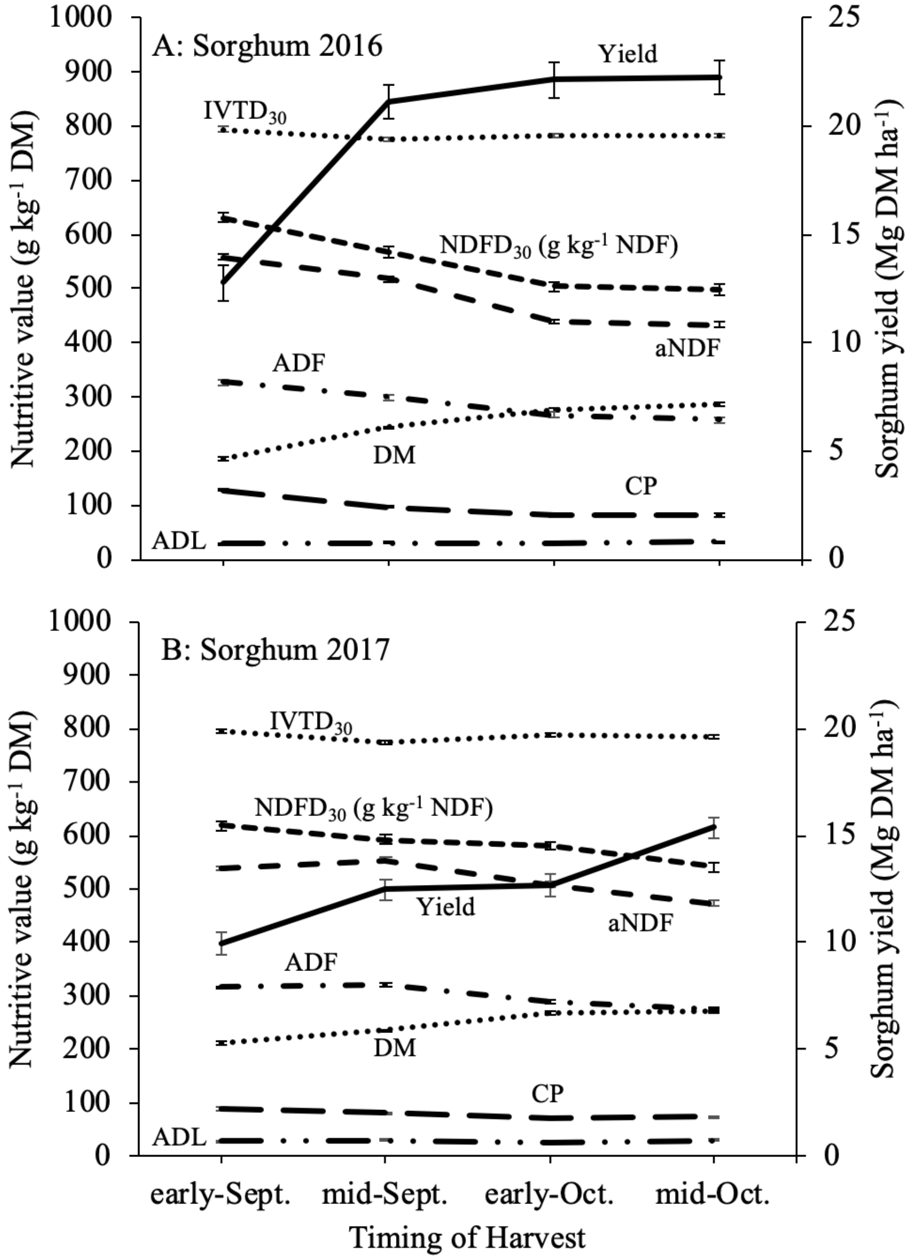

Figure 7.3. Forage sorghum yield and nutritive value as impacted by timing of harvest in 2016 (A) and 2017 (B) in central New York. A fertilizer rate of 224 kg N ha^{-1} was applied at sorghum planting. Error bars represent 1 SE. Values are averaged across five N rates applied at spring dormancy break.

For triticale following +N sorghum, planting time impacted CP concentrations for all spring N rates, where later planting dates resulted in greater CP (Figures 7.4 and 7.5). Across both years and all spring N rates, CP concentrations ranged from 112 to 199 g kg^{-1} DM for the first planting date and 153 to 285 g kg^{-1} DM for the fourth planting date. This increase in CP with later planting dates was also seen in Lyons et al. (2018a), who reported an increase of 9 g CP kg^{-1} DM from a mid-September planting date to a late- to early October planting date. Later planted triticale tends to produce less biomass both in the fall and spring (Lyons et al., 2018a; Lyons et al., 2019c) which could result in smaller, less mature plants at harvest with greater protein content. Later planting dates also resulted in greater triticale DM, $IVTD_{48}$, $NDFD_{48}$, and decreased NDF, ADF, and ADL (Figure 7.4).

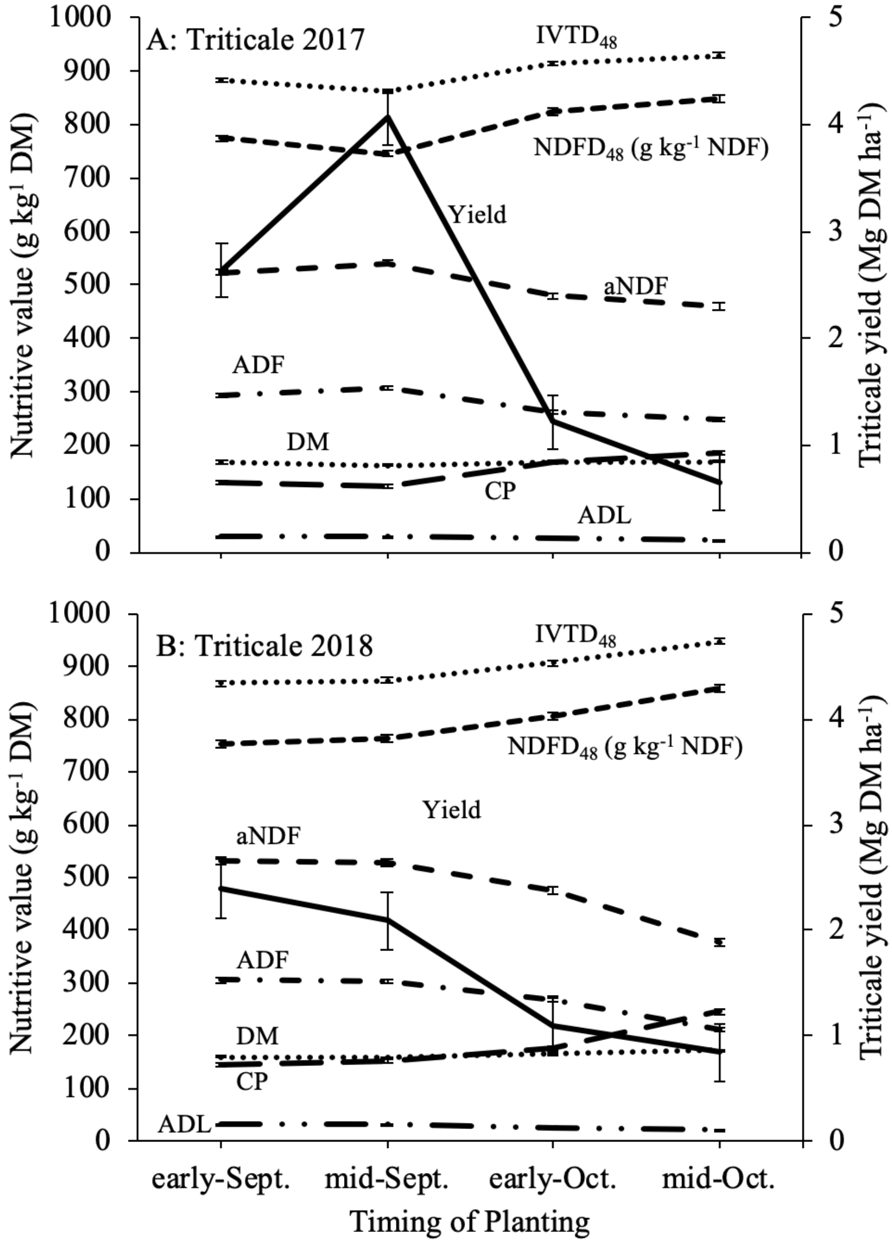

Figure 7.4. Forage triticale yield and nutritive value as impacted by timing of harvest in 2017 (A) and 2018 (B) in central New York. A fertilizer rate of 224 kg N ha^{-1} was applied at sorghum planting in June of each year. Error bars represent 1 SE. Values are averaged across five N rates applied at spring dormancy break.

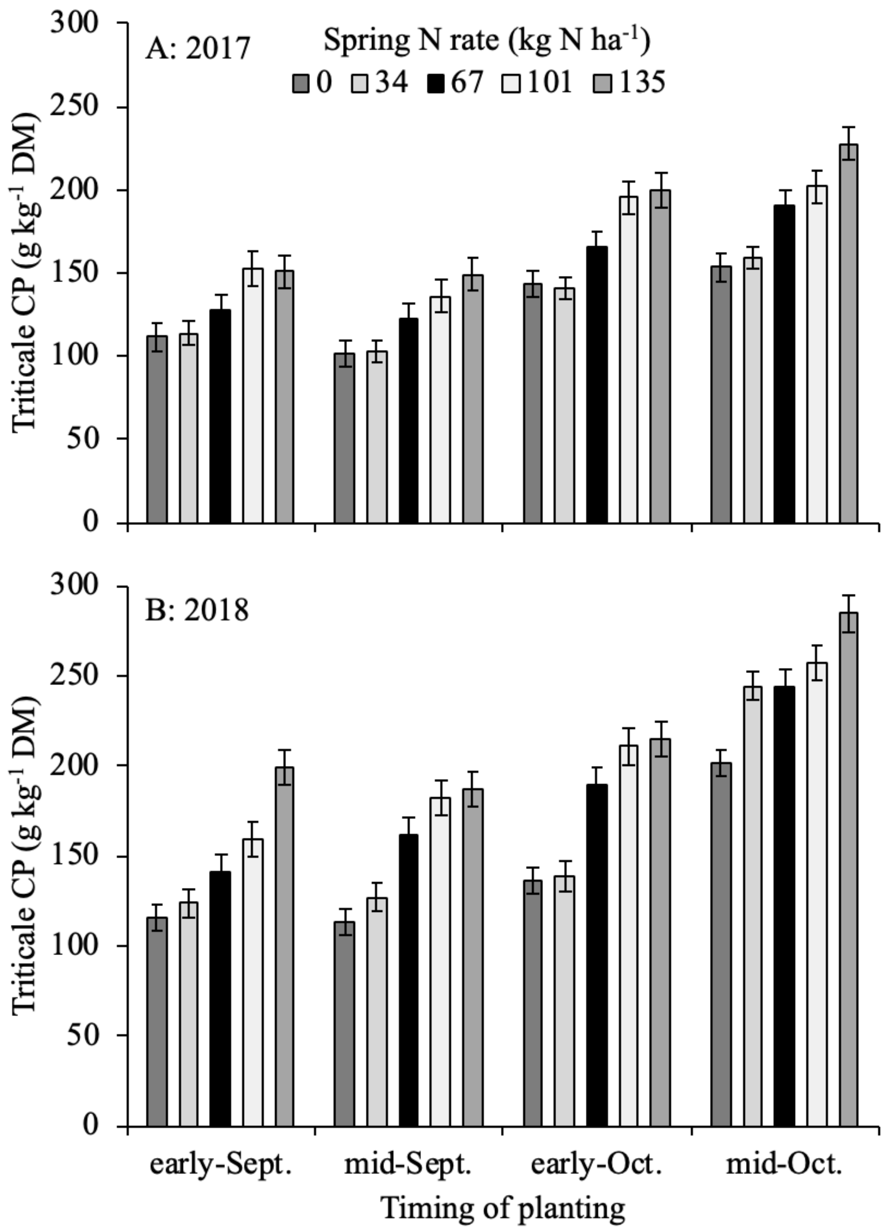

Figure 7.5. Forage triticale crude protein as impacted by planting date at five N rates applied at spring dormancy break in 2017 (A) and 2018 (B) in central New York. Triticale followed sorghum that was fertilized with 224 kg N ha^{-1} at planting. Error bars represent 1 SE.

Triticale Fertilization and Carryover N

In 2016, following the single triticale planting date the previous fall, higher N rates at spring dormancy break caused an increase in soil nitrate at sorghum planting ($P < 0.0001$). Soil nitrate ranged from 6.0 to 14.6 mg kg^{-1} for the 0 and 135 kg N ha^{-1} spring N rates, respectively. In 2017, there was no impact of N applied at spring dormancy break on soil nitrate at sorghum planting but triticale planting time in fall 2016 did have an impact ($P = 0.0093$). Soil nitrate was 5.7, 3.7, 5.0, and 5.9 mg kg^{-1} for the first, second, third, and fourth planting times, respectively. Higher yields for the second planting date may have led to the lower nitrate levels in the soil compared to the other planting dates. The higher than normal precipitation in April (15.6 cm vs. 8.3 cm normal) and May (13.3 cm vs. 8.1 cm normal) could have resulted in residual nitrate loss via leaching prior to sorghum planting, reflected in the lack of differences among spring N rates (Fang et al., 2006).

While there was some influence of spring N and planting date on soil nitrate at sorghum planting, the carryover N was not great enough to impact sorghum yields. There was no effect of N applied at spring dormancy break on sorghum yield (-N plots) at any harvest time except for the final harvest in fall 2017, where sorghum that followed the 135 kg ha^{-1} spring N yielded higher than the sorghum that followed the 34 kg ha^{-1} spring N rate (9.1 vs. 6.0 Mg DM ha^{-1}, respectively; Figure 7.3). There was no impact of N applied at spring dormancy break on the +N sorghum. This suggests that fertilization for a warm-season crop, like sorghum, is essential regardless of the fertilization strategy for the cool-season crop.

Sorghum Fertilization and Carryover N

In 2016, there was an interaction between summer N and sorghum timing of harvest on soil nitrate at sorghum harvest. For both the -N and +N plots, soil nitrate decreased with later harvest dates, but the +N plots had a greater decrease over time. Soil nitrate was 42.7, 28.1, 28.3, and 23.0 mg kg^{-1} for the +N plots at the first, second, third, and fourth harvest dates, respectively (Table 7.4). Spring N application rate also had an impact on soil nitrate at sorghum harvest in 2016, where there was greater soil nitrate at the higher spring N rates (23.2 and 15.5 mg kg^{-1} for the 120 and 0 kg N ha^{-1} treatments, respectively). In 2017, there was no impact of timing of harvest or spring N on soil nitrate. However, the +N plots had a larger numeric soil nitrate value at sorghum harvest than the -N plots (9.5 and 4.4 mg kg^{-1}, respectively; Table 7.4). This discrepancy between the two years was reflected in fall triticale biomass accumulation. In 2016, there was an interaction between summer N and triticale planting date on fall triticale biomass, where the triticale following +N sorghum harvest had greater biomass accumulation than that following -N sorghum harvest at the first planting time (2.7 and 1.4 Mg DM ha^{-1} for the +N and -N plots, respectively; Table 7.4). In 2017, only planting date had an effect on fall triticale biomass accumulation. The 2017 triticale accumulated 0.9, 0.5, 0.1, and 0.02 Mg DM ha^{-1} in biomass for the first, second, third, and fourth planting times, respectively (Table 7.4). Fall growing degree days likely impacted fall biomass production. For all planting times, the 2017 triticale had less GDD between planting and harvest than the 2016 triticale (Figure 7.6).

Table 7.4. Soil nitrate and nitrate, most economic rate of N (MERN), and yield at the MERN for forage triticale grown in rotation with forage sorghum in central New York from 2015 to 2018. Triticale followed sorghum that received either no fertilizer (-N) or N fertilizer (+N) at planting (summer N) and was planted at four different times in the fall, ranging from early September to mid-October. Triticale was harvested at the flag-leaf stage in May of each year.

Year	Summer N	Plant date	Soil NO_3^- at triticale planting†	Soil NO_3^- at green-up‡	Soil NH_4^+ at green-up‡	Fall GDD§	Fall biomass	MER N	Yield at MERN
			---------- mg N kg^{-1} soil ----------				Mg DM ha^{-1}	kg N ha^{-1}	Mg DM ha^{-1}
'15-'16	na¶	10/16	na¶	8.4	na¶	503	na¶	86	4.0
'16-'17	-N	9/2	23.9	2.3	15.0	1102	1.38	0	2.4
		9/16	12.5	2.5	13.8	827	0.50	118	4.0
		10/7	15.1	2.3	13.2	483	0.06	0	0.2
		10/14	26.6	2.1	12.4	394	0.04	0	0.2
	+N	9/2	23.3	2.2	12.9	1102	2.69	0	1.1
		9/16	22.2	1.6	14.4	827	1.06	0	3.6
		10/7	15.3	1.5	12.4	483	0.08	0	0.8
		10/14	17.7	1.3	15.1	394	0.05	0	0.4
'17-'18	-N	9/13	11.8	2.8	16.4	929	0.79	0	1.8
		9/21	9.8	3.2	15.5	772	0.50	> 134	5.8#
		10/4	5.7	3.5	14.5	544	0.09	65	1.1
		10/20	6.1	3.3	16.9	293	0.02	0	0.1
	+N	9/13	5.0	3.1	13.7	929	0.98	0	2.3
		9/21	7.2	3.4	12.8	772	0.44	0	1.6
		10/4	6.2	2.6	13.2	544	0.09	0	0.7
		10/20	5.2	4.0	14.6	293	0.02	0	0.1

†Soil samples at triticale planting were analyzed for Morgan extractable NO_3-N (Morgan, 1941).

‡Soil samples at spring dormancy break were analyzed for 2 M KCl extractable NO_3-N and NH_4-N (Keeny and Nelson, 1982)

§Growing degree days calculated by subtracting the lower threshold temperature for triticale (0°C) from the average daily temperature (°C): [(Temperature$_{max}$ – Temperature$_{min}$)/2.

¶na, not applicable. Sampling began at triticale harvest in 2016.

#No yield plateau was reached so yield at the highest N rate (134 kg N ha^{-1}) is reported.

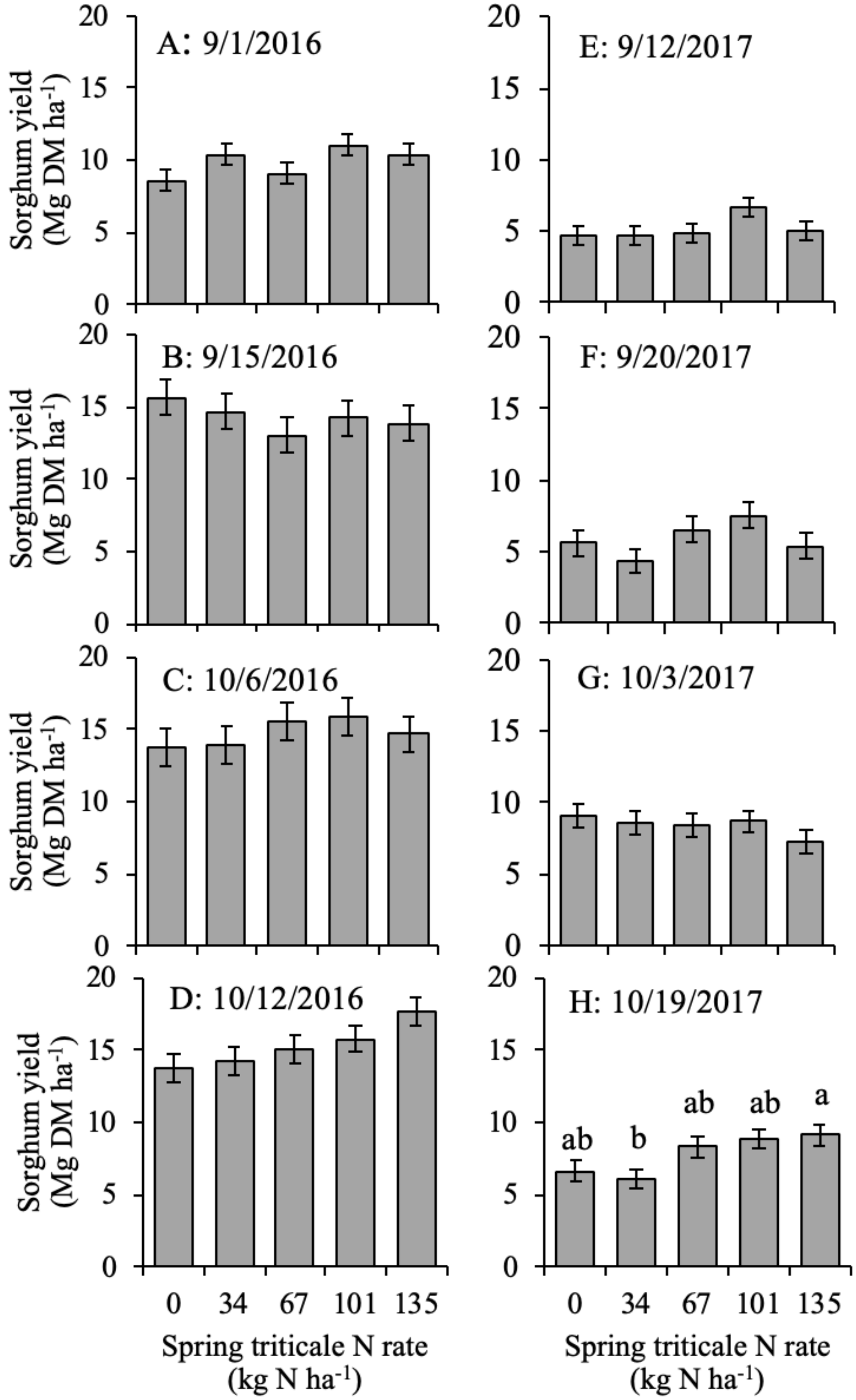

Figure 7.6. Sorghum (no additional fertilizer at planting) yield as impacted by N applied to triticale at spring dormancy break at four different timings of harvest in 2016 (A, B, C, and D) and 2017 (E, F, G, and H) in central New York. Harvests took place in early-mid September (A and E), mid-late September (B and F), early October (C and G), and mid-October (D and H). Error bars represent 1 SE.

The following spring of each year, soil nitrate concentrations were at baseline levels (Table 7.4). This suggests that soil nitrate present in the fall was either taken up by triticale or lost over the winter months via leaching (Ketterings et al., 2003; Sadeghpour et al., 2017). It is also possible that the 0 to 20 cm soil samples were not deep enough to detect additional residual soil nitrate in the spring.

Triticale MERNs in spring 2017 and 2018 were impacted by rotation management. For the -N plots, the second planting time for the 2017 triticale had a MERN of 118 kg N ha^{-1}, 32 kg N ha^{-1} greater than the initial MERN in spring 2016, with a similar yield at the MERN to the 2016 triticale (4 Mg DM ha^{-1}; Table 7.4). The second planting date for the 2018 triticale had an even higher MERN than the previous two years (> 134 kg N ha^{-1}) with a maximum yield of 5.8 Mg DM ha^{-1}. The third planting date for the 2018 triticale also had a positive MERN of 65 kg N ha^{-1}, with a yield at the MERN of 1.1 Mg DM ha^{-1}. The remaining planting dates for the -N plots and all of the +N plots had MERNs of 0 (Table 7.4). The earliest planted triticale may have had enough GDDs in the fall to take advantage of any residual fall N and establish a robust root system to not require additional N at dormancy break (Figure 7.7). The second and third planting times had adequate GDDs to properly establish root systems in the fall but did not likely have as well developed root systems as the earlier planted triticale. So, while these plots were able to make use of residual fall N from the +N plots, the -N plots needed additional N at dormancy break to reach optimum yields. In contrast, the triticale planted in October (third and/or fourth planting times) may not have accumulated enough biomass to take advantage of residual fall N.

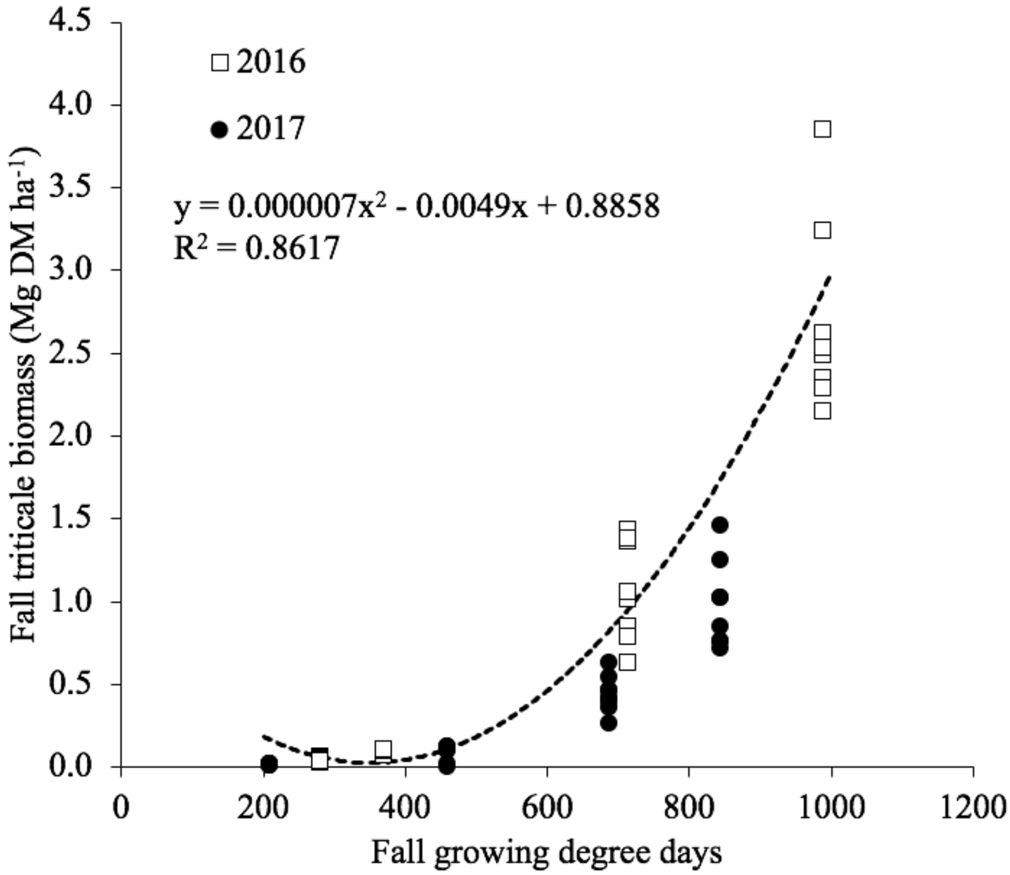

Figure 7.7. Fall triticale biomass and corresponding fall growing degree days (GDD) for 2016 and 2017 in central New York. Triticale was planted at four different times in the fall. Growing degree days were calculated by subtracting the lower threshold temperature for triticale (0°C) from the average daily temperature (°C): [($Temperature_{max}$ – $Temperature_{min}$)/2.

In addition, the later planting dates had lower spring yields, reflecting lower N requirements. These plots may have had sufficient N in the soil from organic matter mineralization (Ketterings et al., 2003). These results suggest that triticale following fertilized sorghum may not need additional N at dormancy break in the spring to reach optimum yields. If some additional spring N is required for higher CP concentrations, a small amount (22 to 34 kg N ha^{-1}) could be applied as triticale responds in CP concentration to N addition beyond what is needed for yield (Lyons et al., 2019c).

CONCLUSIONS

Double-cropped forage triticale and forage sorghum performance is dependent on management of fertilizer N, timing of sorghum harvest and triticale planting, and weather. In warm, dry years, harvesting fertilized sorghum once 1150 GDD have accumulated after planting can support both forage sorghum and forage triticale yields without having to fertilize triticale at spring dormancy break. In cool, wet years (fewer than 1150 GDD) harvesting fertilized sorghum at the soft dough stage will maximize sorghum yields. Harvesting sorghum before the soft dough stage resulted in greater digestibility and CP concentrations and lower starch and DM content. Triticale yields can be maximized if planted by mid-September. If higher triticale CP is needed, a small amount of N fertilizer can be applied in the spring.

ACKNOWLEDGEMENTS

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